DEVELOPMENT OF TECHNIQUES TO MANUFACTURE FRP PRODUCTS USING RAPID TOOLING

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CERTIFICATE

It is certified that the work contained in the thesis entitled **"Development of techniques to manufacture FRP products using Rapid Tooling"**, *by* **Sunil Kumar,** *has been carried out under my supervision, and this work has not been submitted elsewhere for a degree.*

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Dedicated to

MY PARENTS

ABSTRACT

In the present work, a new technique has been developed for manufacturing FRP products from fabric based prepregs. The technique is based on one of the indirect rapid tooling (RT) techniques, in which a pattern is used to make the moulds. In the technique, a matching die-set of a low temperature alloy of melting point 200° C is made by casting process. This die-set (mould) is subsequently used for manufacturing FRP products. An uncured preform of the product is prepared by stacking prepregs layer by layer and then this preform is subjected to an appropriate temperature and pressure cycle for curing. Using this new technique various products like a flanged cone, several cylinders and a table tennis bat are made. On the basis of several quality tests performed on the products, a comparison is made between the products made by the new technique and the conventional tooling to predict acceptability of new technique for manufacturing of the FRP products. For making die-sets of low temperature alloy from complex shaped patterns, a new method " Parting Line Concept" has been developed. Using parting line concept, die-sets for various FRP products are made. These die-sets are subsequently used for making FRP products. Three cylindrical products; one hollow cylinder and two cylinders with metallic core are made. One table tennis bat is also made using parting line concept.

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

Composite material

A material having two or more than two distinct constituent materials or phases is considered as a composite material when the constituent phases have significantly different physical and chemical properties and thus the composite properties are noticeably different from the constituents' properties.

There is no doubt about the role of steel, aluminum, non-reinforced plastic and other engineering material in different fields of engineering. But FRP (fiber reinforced plastic) composite is becoming more and more popular amongst the designer because of its unique properties like high tensile strength, corrosion resistance, high modulus and light weight. FRP is being used in aerospace and sports industries for years due to its attractive properties.

Use of composite materials is spreading from cutting edge technology to everyday application like fuel cylinder of natural gas, blades of wind powered turbines, support beam of highway, bridges and even in paper making rollers. Thus, FRP composite is going to play an important role in power generation and transmission, bridge building, surface transportation, automobile railways and the telecommunication industries in future.

Rapid tooling

Making of die-set (upper and lower parts) using conventional process is time consuming, costly due to high machining cost, and complex. It requires skilled labors and high expertise. New unconventional tooling methods (like Rapid Tooling) are becoming more popular because a complex mold (die-set) can be prepared faster and cheaper than conventional die-set. By definition, Rapid tooling (RT) is a collection of technologies and processes that delivers components in a fraction of time as compared to conventional tooling method. There are various techniques of RT available, but it can be classified in two major groups, indirect and direct RT processes. RT is useful where tool geometry is complex and it is difficult to make tool using conventional machining process.

1.2 LITERATURE SURVEY

1.2.1 Manufacturing of FRP Products

Manufacturing of even simple shaped FRP products is not an easy task and manufacturing of complex shaped products is difficult task and still not developed well. Manufacturing of FRP composite products is mainly based on casting, the principles of metal forming and cutting are not directly applicable. Moreover casting of FRP components is more difficult than casting of metals where liquid metal has good flowability and it can easily flow in gating channel to fill a cavity. In manufacturing of FRP components, polymer being liquid with low viscosity has good flowability but fibers with their high stiffness are not only solid but do not drape easily over high curvature. There is one more difficulty in casting of FRP; formation (curing) of composite material combines with the shaping of material, so temperature and pressure cycle for curing should be such that shaping of material is completed before setting (solidification) of polymer. Several methods have been developed for the manufacturing of products of fiber reinforced composite material [Parkyn, 1970; Aggarwal and Broughtman, 1990;

Hollaway, 1994; Kumar, Goel and Bandhopadhyay, 1995; Mangalgiri, 1999; Kumar, 2000]; some of them are

1. Filament winding
2. Pultrusion method
3. Bagging technique
   (i) Vacuum bagging technique
   (ii) Pressure bagging technique
4. Matching Die-Set technique
5. Resin Transfer Molding (RTM)

Filament winding is one of the methods of manufacturing of FRP composite products. Filament winding technique is shown in Fig.1.1. The fiber roving may be wetted just prior to the winding or resin impregnated tape may be used that is heated before winding. A tape, wetted with resin, is wrapped around a rotating mandrel to form a continuous structure. The rotation of mandrel and longitudinal translation of the tape is controlled to have proper orientation of fibers. Fiber orientation is the decisive factor in strength of the FRP composites. The tension of the fiber is also controlled to have desired compactness. Filament winding technology offers a high degree of automation. This technique is now well developed but it is limited to hollow and axisymmetric structures. Rocket structural bodies, pressure vessels, tubes are usually produced with this technique. The technique has its own limitations; complex shapes are difficult to obtain, the external surface finish of the product is poor and winding at low angles is difficult.

In Pultrusion method, continuous fibers are wetted with epoxy, squeezed in a preformer to remove excess epoxy, and trapped air (Fig.1.2). Then wetted fibers are pulled through a heated die for curing. This process is similar to the extrusion of aluminum with a difference that aluminum section is pushed instead of pulling. Various sections like rectangular, circular, hexagonal, and tubular of FRP composite can be mass-produced having long lengths. In this method, products can be made entirely of unidirectional fibers but usually some chopped fibers are added to improve the transverse

strength. The pultruded FRP composite products have high strength and high fiber volume fraction. The tooling is not very expensive and pultruded sections can be made of standard dimensions. But pultrusion method is not suitable for making products of varying cross section and of curved shaped.

Bagging Techniques are commonly used in Aerospace industries for making complex shaped polymer composites. Prepregs, which are semi-cured preimpregnated tapes of glass fibers, are the raw material for bagging technique. Prepregs are cut in shape and stacked together to make the preform (uncured form of the product) of the product Then it is compressed under pressure and temperature for final curing. Bagging technique is mainly of two type namely vacuum bagging and pressure bagging

In vacuum bagging technique, preform is bagged and vacuum is created in the bag, resulting into compression of the prepreg, through one atmospheric pressure (Fig. 1.3 a). Over a single die several layers are stacked of the materials like release film (for easy removal of cured product), preform of the product, perforated separator, bleeder and vacuum bag. When vacuum is created inside the bag, outside atmospheric pressure compresses the bag and the preform. There is one limitation in this technique that maximum pressure on preform is limited to only one atmospheric, which is usually found not adequate. However this technique is simple and inexpensive.

In pressure bagging technique, the bag is created similar to that of vacuum bagging technique that is stacking of similar material over the die, but with a difference that entire assembly is placed in an autoclave. In the autoclave an atmosphere of compressed nitrogen is generated. Thus high pressure can be applied on the preform which is not possible in vacuum bagging technique from the inside of the bag . The vacuum system also works parallel to pressure system to bleed out air and volatile gases from inside of the bag. Pressure bagging technique works quite efficiently but it has some limitations. Tooling becomes expensive and after making one component entire bagging material is discarded. Many airplane parts are made through this technique. This technique is so expensive that daily life products can not be made through this technique.

In matching Die-Set technique a preform is compressed for curing in between the die-set (Fig.1.4). A safe release agent is applied on the surfaces of the die and punch. Prepregs are taken out from the freezer and cut into the desired shape and stacked over the die layer by layer. The number of layers to be stacked depends upon the desired thickness of product. After stacking, punch is placed over the die with proper orientation and preform is cured in a press with heated platens. This technique for making FRP product is used in present work.

In Resin Transfer Molding (RTM) technique, a matching die-set is prepared and the reinforcement is placed in the lower half of matching die-set (Fig.1.5). After the die-set is closed and clamped, resin is pumped under pressure into the die cavity. The resin wets the reinforcement and cures to form the composite part. This method is not suitable for use with high-temperature epoxy system, which have relatively high density at curing temperature. To process good quality parts using RTM, one must use a epoxy with a low enough viscosity and sufficiently long pot-life to completely infiltrate the preform.

1.2.2 Rapid Tooling

Conventional die making is a time consuming, expensive and complex way of making die. It requires high expertise and skilled labor. Thus, quick and easy methods for manufacturing of die are required. Development of low temperature alloys, silicon rubber, resin etc. have made it possible to make die in less time and cheaper than conventional process of die making. These developments led to the tooling method called Rapid Tooling. There are various techniques of RT available, as discussed earlier it can be classified into two major groups' i.e. indirect and direct RT processes. In indirect RT process, starting point is the pattern, for which tool is to be made. Using this pattern, tool is made which is used to make products. In direct RT process tool is directly made in

layers using Rapid Prototyping (RP) process. In this process, CAD data available is used to design the mold and mold is made using RP process.

Several techniques of Indirect Rapid Tooling are [Paquin and Crowely, 1987; Stanley, 1950, Dallas, 1967; Ostergaard, 1967; Paquin and Crowely, 1987; Dickens, 1996; Kumar-2, 1998; Allsop,1983; Bhatt, 2000]:

(i) Silicon Rubber molding
(ii) Epoxy Tooling
(iii) Spray Metal Tooling
(iv) Electroforming Tooling
(v) Polyurethane Tooling
(vi) Vacuum Casting
(vii) Low Temperature Alloy Tooling

The technique to produce silicon rubber mold involves suspending the master pattern in a vacuum box and pouring liquid resin around the pattern. After curing, the mold is cut along the desired parting line and is opened. The master pattern is taken out which leaves a cavity in the mold segments. The mold segments are mounted on an injection molding machine to produce the product. Silicon rubber molding enables fabrication of flexible mold, which can be used for manufacturing parts with intricate details and undercuts. Silicon rubber molds have high chemical resistance, low shrinkage and high dimensional stability. They are however, can not be remolded.

The Epoxy Tooling process requires a master pattern, which is strategically placed in the molding box. A safe release element is applied on the surface of the master pattern, which facilitates the easy removal of the master pattern. An appropriate two component (epoxy and hardener) epoxy is poured in the molding box. After curing, master pattern is removed from the epoxy mold. Some filler materials like aluminum and steel powder can be added to epoxy system to increase the hardness, impact resistance and wear strength. The durability of the epoxy mold is not high.

Spray Metal Tooling process uses a high velocity electric arc metal spray generating system to deposit finely atomized molten metal particles on the surface of the master pattern to create a shell mold of metal. The metal wire is supplied from a spool and melted by an arc produced in the spray gun. A jet of compressed air propels and breaks the molten metal into fine particles, which deposit on the surface of the master pattern. The low melting point metal or alloy of aluminum, copper, zinc or nickel is usually used for making tool. The surface of master pattern is coated with a release agent which acts as a anchor for the initial spray of the metal spray, provides adequate temperature resistance and facilitates easy removal of the master pattern. The metal shell formed can be used for sheet metal forming and injection molding. The porosity and low strength of spray metal mold results in shorter life.

Electroforming tooling process involves different steps, first step is coating of the conducting material over the master pattern then an electroplating solution is deposited on the pattern, lastly another material usually ceramic is deposited and cured to make tooling. This process is a fast fabrication of nickel-ceramic composite tooling for intermediate volume plastic-injection molding runs. Usually a plastic master pattern is used which is coated with a conductive silver based material and placed in a electroforming bath of nickel alloy, where a thin layer of nickel is plated over it. After electroforming, ceramic is deposited on it in a vacuum chamber. It is then cured for about a day. After curing, pattern is removed (Fig.1.6).

Polyurethane Tooling is a very effective method to produce molds as flexible molds and unlike Silicon rubber tooling is less expensive. Both molds and models can be made from polyurethane. For making a mold, master pattern and molding box is coated with releasing agent. Master pattern is placed in the molding box then polyurethane resin is poured in the molding box through a tube and resin is allowed to harden. After hardening of resin, second part of the die is made and pattern is removed.

Vacuum Casting is similar to silicon rubber molding with the difference that whole process is carried in the vacuum. Air present in silicon rubber resin is removed in vacuum chamber which increases the dimensional accuracy. In vacuum casting a master pattern fitted with gates is placed in the vacuum chamber. RTV (room temperature vulcanization) silicon rubber is poured around the pattern. Then the whole system placed in a side heating chamber for final curing. After curing mold is cut in two parts along the parting line.

Low temperature alloy casting is also one of the important tooling method. Low temperature alloys are those alloys, which melt at low temperature. Low temperature alloy can be used for making die sets with accurate matching. Development of different low temperature alloy creates the path for the emergence of this technique. By this method die set can be created with in a few hours in contrast to conventional method, which takes a long time to prepare and requires high expertise. In this method, a molten low temperature alloy is poured on both side of the pattern to make matching die set. The pattern can be made of materials like mild steel, aluminum, etc. Choosing appropriate percentage of alloying element can control the melting point of the low temperature alloy. MCP-200 is used as the low temperature alloy. Alloy is designated as MCP 200, where MCP refers the company name that is Mineral & Chemical Product, Geneva Switzerland and numeric digit denotes melting point of the alloy. They have good releasing properties and they do not adhere with pattern and molding box material. This alloy is composed of Bismuth, Tin, Indium and Zinc. Exact composition is not known because company does not disclose the composition. Indium is used to obtain extremely low melting point alloy. Since nearly all metals contracts on solidification, Bismuth is added which has a rare property of expanding 3.3 % by its volume on solidification. By mixing different metals in appropriate ratio different low temperature alloy are obtained whose dimension does not change much on solidification.

In last 4-5 decades, mostly aerospace industries have taken interest to develop manufacturing techniques of FRP composite products because these suit them very well. A polymer composite component reduces the weight and increases the payload. In

aerospace industry, cost of component is not of high priority. Techniques developed by them are very expensive and production rate is slow. For making polymers composites, in daily life, better production methods are to be developed which should not be expensive and their production rate should be high. P.Kumar [Kumar, 2000] suggested rapid tooling techniques for making FRP composite products. FRP composites require finite curing time therefore one set of die is unlikely to have fast production rate. Thus multiple dies can be used for competitive production rate. Making of multiple dies using conventional method will be very expensive; therefore there should be inexpensive way of making dies. The application of rapid tooling is likely to have high potential for making die-set economically. A low temperature alloy is employed for making die set. This process of rapid tooling is fast, easy and inexpensive as alloy can be melted again for other set of dies. The tooling takes only 3-4 hours and therefore multiple dies can be made in a short time. Furthermore, if a FRP product is not found suitable, the die set can be melted down and a new set with modified pattern can be prepared in short duration. Such flexibility, low fabrication cost and fast preparation of die is not possible with conventional method of making die set.

1.3 OBJECTIVES OF THE THESIS

In the present work, several FRP components are made such as a flanged cone, a hollow cylinder, a cylinder with metallic core and a table tennis bat. For flanged cone product a conventional die-set and a Rapid tooling die-set (low temperature alloy technique) is made. Then comparison is made between conventional tooling and rapid tooling for producing FRP Product. Die-set for single piece and complex pattern is made through Parting Line Concept.

1.4 THESIS LAYOUT

In the present Chapter, an introductory description of composite materials and rapid tooling is given. Then conventional method of making dies is discussed along with advantages of rapid tolling over the conventional method. Different rapid tooling

processes were discussed with their advantages and disadvantages. In chapter 2, process of making FRP product through metallic die set is discussed. A flanged cone component is chosen for making FRP product, and die design and process to make component is discussed. In Chapter 3, Low Temperature Alloy rapid tooling technique is discussed and die-sets for flanged cone is made. Comparison between conventional tooling and Rapid tooling is made for making FRP products. In Chapter 4, a concept of parting line is developed for making die-set from the single piece and complex patterns. Using this concept, die-set for a cylinder and a table tennis bat are made and then FRP components are made through these die-sets.

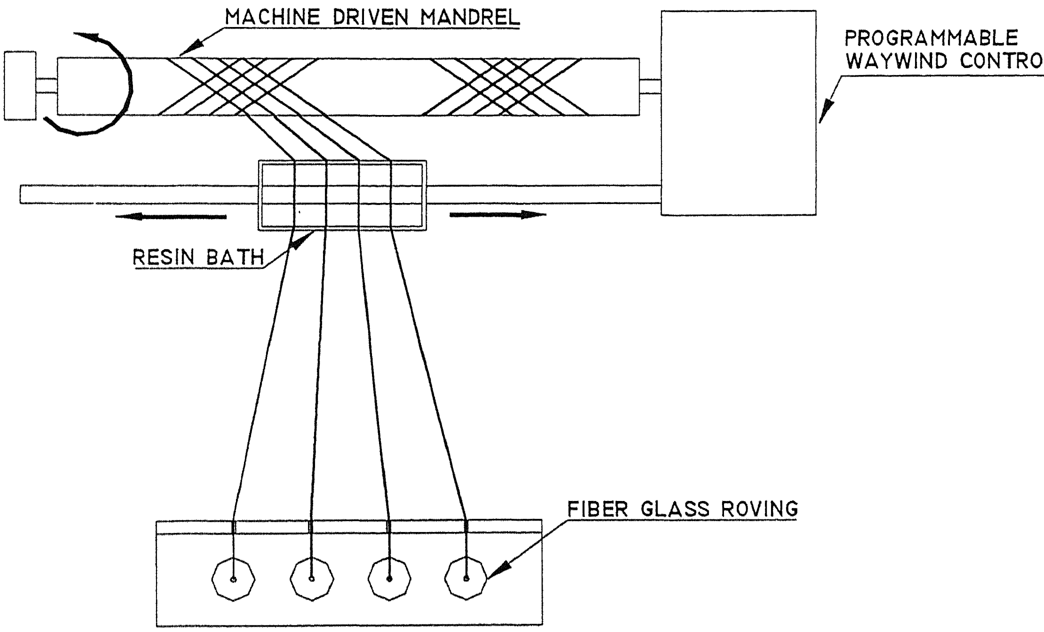

Figure 1.1 Filament Winding operation

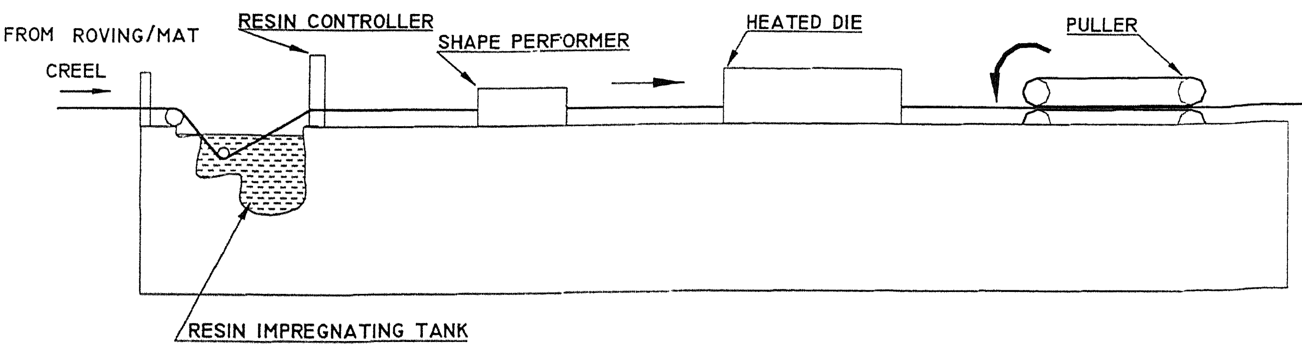

Figure 1.2: Pultrusion Operation

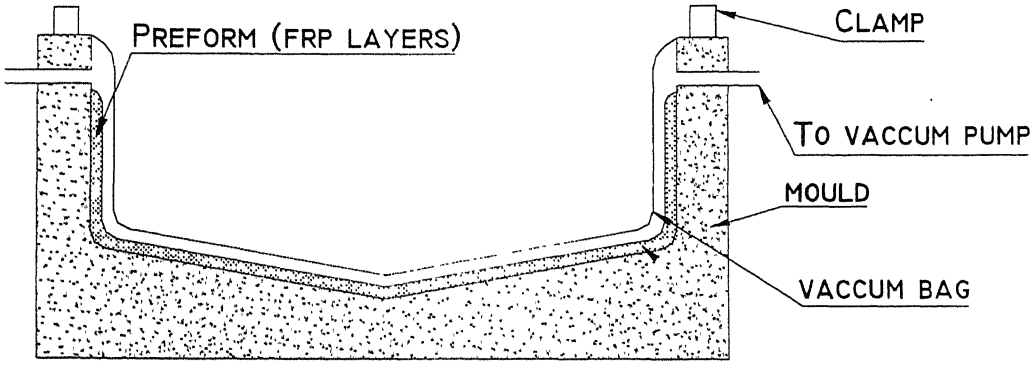

Figure 1.3.a: Vacuum-Bag molding

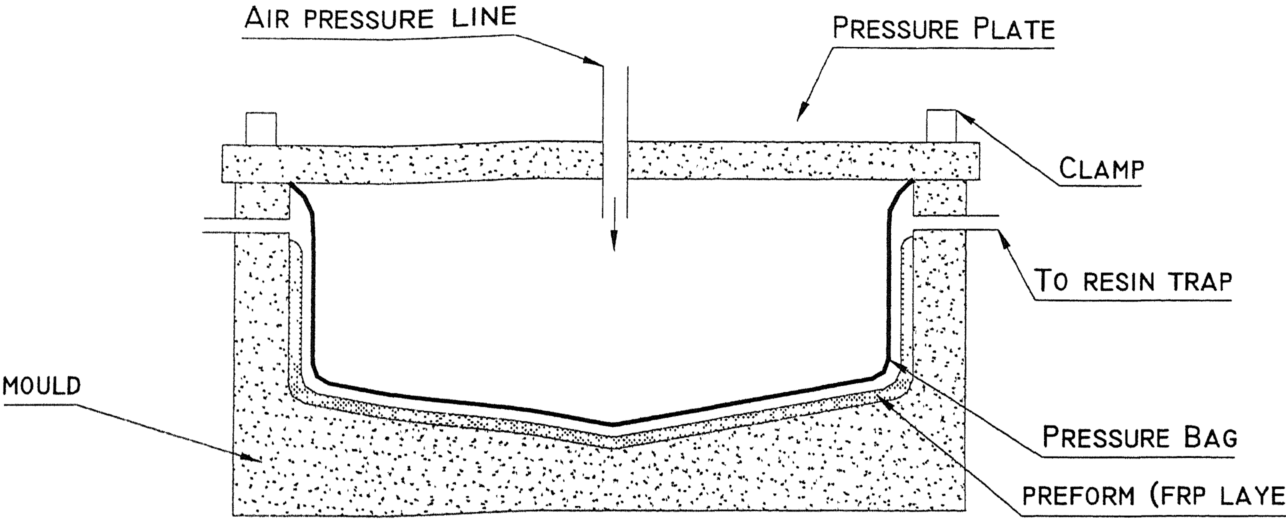

Figure 1.3.b: Pressure-bag molding

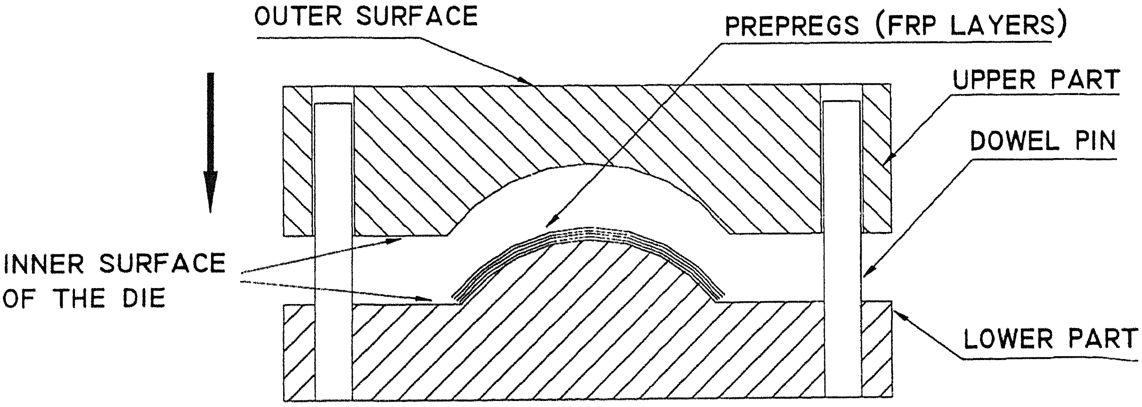

Figure 1.4: Matching Die-Set

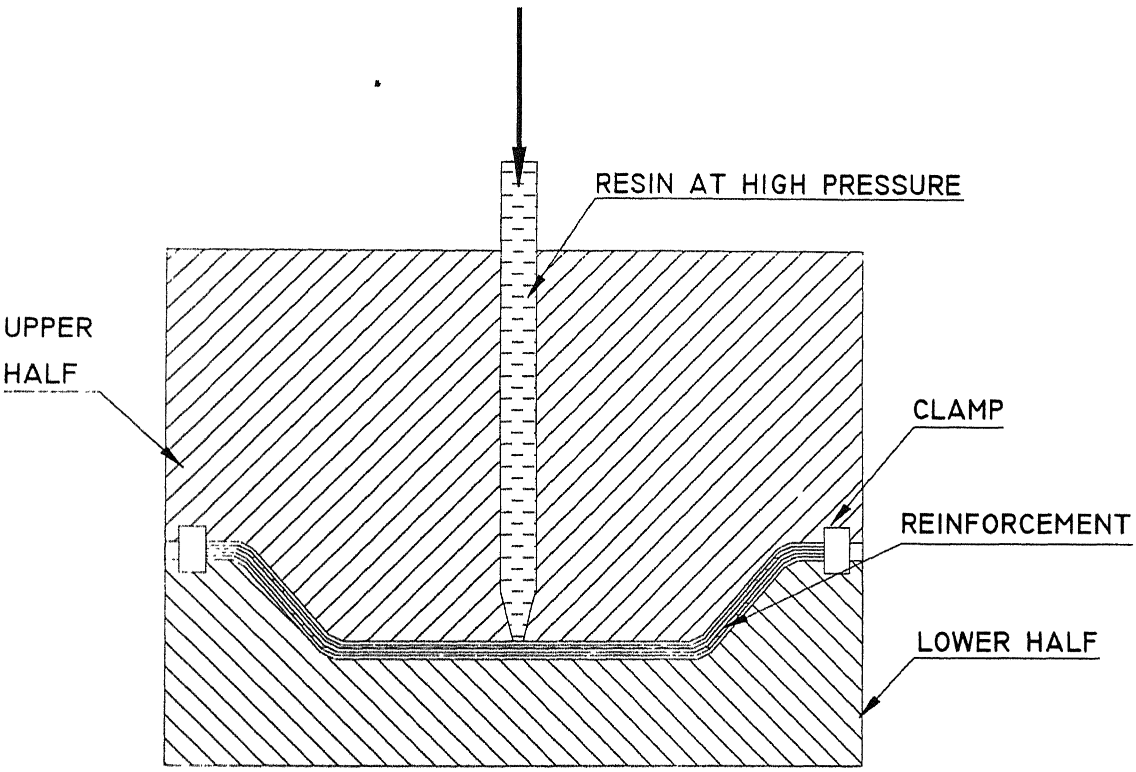

Fig.1.5: Resin Transfer Molding

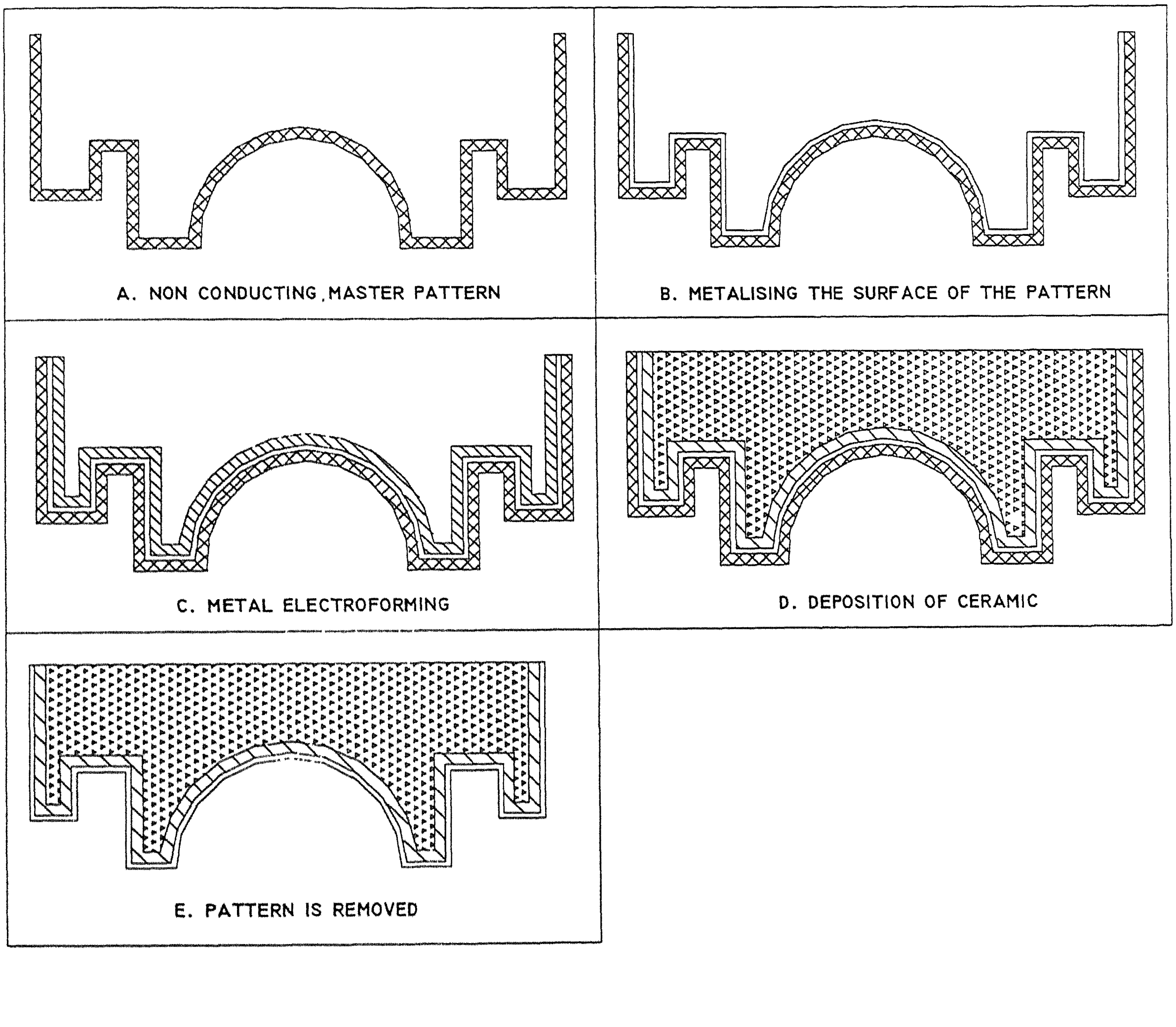

Fig.1.6 Elecroforming Tooling

CHAPTER 2

FRP PRODUCT THROUGH CONVENTIONAL TOOLING

2.1 INTRODUCTION

Different techniques are employed to make FRP composite products and all of them require a pressure and temperature cycle for curing. Pressurizing a composite lamination serves several functions. First, it removes trapped air between layers. Second, it compacts the fiber layers for efficient force transmission among fiber bundles and prevents shifting of fiber orientation during cure. Finally it optimizes the volume fraction of the fibers in the FRP products. Several production methods adopted for making FRP products are:

1. Filament winding
2. Pultrusion method
3. Bagging technique
    a. Vacuum bagging technique
    b. Pressure bagging technique
4. Matching Die-Set technique

The first three methods are described in Chapter1, and the method of matching die set is discussed and employed in this work. In matching die set technique, a preform (an uncured form of the product which is prepared by stacking layers of prepregs) is compressed for curing in the heated die-set. Prepregs are pre assembled and impregnated fibers or fabrics shown in Fig.2.1. Prepregs are cut in right shape and fiber orientation. A safe release agent is applied on the surfaces of the upper and lower die. Prepregs are taken out from the freezer and cut into the desired shape and stacked over the one half of the die-set layer by layer to prepare the preform. The number of layers to be stacked depends upon the desired thickness of product. After stacking, another half of die-set is

placed over the first half having preform. Now the die-set is placed in a hydraulic press with heated platens. And a temperature and pressure cycle is applied on the preform for curing. In present Chapter, a component has been chosen for making FRP product, that is a flanged cone (as shown in Fig.2.2). The component is made by two different technique, (i) through a matching die set made of mild steel and (ii) through the rapid tooling method in which a die-set of a low melting point alloy is made. This chapter deals with the steel mould (die set). In Chapter 3, the technique of rapid tooling for making the die-set will be discussed. Thus the same component is made using conventional and rapid tooling; then a comparison is also made in rapid tooling and conventional tooling products.

2.2 PRODUCT DEFINITION

This product has a frustum of cone having an integral flange at its base (Fig. 2.1). The flange has the outer diameter of 100 mm and thickness of 4 mm, cone has thickness 3.2 mm and angle 30°. The total height of the product is 25 mm.

2.3 DIE DESIGN

2.3.1 Material

Mild steel is chosen as the die material because it has several attractive properties like reasonably high strength, easy to machine, good thermal conductivity and high stiffness. The mild steel can easily sustain the compressive load, which is developed in the die during the curing of the preform under pressure. However, high strength die steel is not required because making a FRP product is a molding process and high stresses are not developed. The cured product can be taken out from the die easily because mild steel adheres less to epoxy. Since mild steel has a reasonably high thermal conductivity, heat can flow easily to preform through the die. The deformation of the die parts is negligible under the applied compressive load because mild steel has very high modulus of rigidity.

2.3.2 Different Components of the Die Set

An assembly drawing of die-set is shown in Fig.2.3.a. Die-set has four components:

(i) Lower Die (in two parts)

(ii) Upper Die

(iii) Setting Cone

The components are designed to have an easy disassembly after the curing of the FRP product. All components of the die are shown in Fig.2.3.b.

Lower die has two parts, the base plate (Fig.2.4) and the cone (Fig.2.5). Base plate is a circular plate having diameter 110mm, which is 10mm more than the diameter of flange of the product to take trimming and finishing allowances. Base plate has a counter boring in which cone rests and assembled to base plate with an M10 bolt. Disassembling of both parts is done after the completion of curing of preform, which facilitates the removal of the product. The cone is designed to have a protruding portion at the top, which goes in a hole of upper die for better alignment of upper and lower dies.

Upper die is made in single part (Fig.2.6). It has a side hole of ϕ5mm,which is meant for removal of excess epoxy from upper side of preform. Another hole of ϕ10.2 mm on its top surface is made for better alignment of upper and lower die, in which protruding portion of lower die is fitted.

Setting cone is used to set the thickness of the product flange (Fig.2.7). The setting fixture is placed on the conical part of lower die, and upper die is placed on it which sets the thickness of conical part, then by placing shims of appropriate thickness on the counter bored part of the lower die the flange thickness is controlled.

2.4 SPECIFICATIONS OF THE PREPREG MATERIAL

The Prepregs are preassembled and impregnated fibers or fabrics. In the present work glass fabrics are used as the reinforced material in the epoxy matrix. The main advantages of the glass fibers are the low cost and the high strength. The main disadvantages of glass fibers are relatively low modulus of rigidity, poor abrasion resistance and poor adhesion to polymer matrix mainly in the presence of the moisture. Therefore a coupling agent, SILANE, is used for increasing the adhesion.

2.4.1 Fibers

For structural composites mainly two types of the glass fibers E-glass and S-glass are used. In the present work E-glass fibers are used for reinforcement. The typical compositions of the E-glass fibers are given in Table 2.1[Agarwal and Broutman, 1990].

Table 2.1: Composition of the E-glass fibers

Material	% Weight
Silicon oxide	54.3
Aluminum oxide	15.2
Calcium oxide	17.2
Magnesium oxide	4.7
Sodium oxide	0.6
Boron oxide	8.0

Typical properties of the glass fibers are given in Table 2.2[Agarwal and Broutman, 1990].

Table 2.2: Properties of the E-glass fibers

Density gm/cc	2.54
Tensile strength MPa	3450
Elastic modulus MPa	72.40
Range of diameter μm	3-20
Coefficient of thermal expansion 10^{-6} / °C	5.0

Glass fibers available in different form are:

(a) Roving

(b) Chopped Roving

(c) Chopped-strand mat

(d) Woven roving

In present work, woven fiberglass fabric is used to make products. Fiberglass yarn is woven into fabric by standard textile operations. The properties of the product depend on the fiber construction, that is, the number of yarns per inch in each direction, weave pattern and yarn type.

Specifications of the Glass Fibers

The specification of the glass fabric which is used in the present work is as following:

Density of Fabric--------------------------- 146 gm/m^2

No. Of yarns per inch of fabric----------- WARP: 40

WEFT: 36

2.4.2 Polymers

Polymers (plastics) are widely used matrix materials for fiber composites. The matrix serves to bind the fibers together, transfers load to the fibers and protects them

environmental attack, and damage due to handling. Low-cost easy processibility, good chemical resistant and low specific gravity are main advantages of the polymer. On the other hand, low strength limits their use.

In present work, thermoset epoxy resin is used as the matrix material. Epoxy system is superior to polyesters particularly about adhesion with a variety of fibers, moisture resistance and chemical resistance. Typical properties of thermoset epoxy-resin used in the present work is given in Table 2.3 [Agarwal and Broutman, 1990].

Table 2.3: Typical properties of the Cast Epoxy Resin (at 23° C)

Density, gm/cc	1.2-1.3
Glass transition temperature (° C)	150-200
Tensile strength (MPa)	55-130
Tensile modulus (GPa)	2.75-4.10
Water absorption (% in 24 hr.)	0.08-0.15

2.5 PROCEDURE TO MAKE FRP PRODUCT

2.5.1 Preparation of the Die

The die-set is cleaned properly with acetone to remove oil or grease from the surface of die. Then SAFERELEASE # 30, water based mold release agent (manufactured by AIRTECH INTERNATIONAL INC., CALIFORNIA, USA), is used. The material of the safe release is Teflon. The surface of the die is coated with the release agent, the solvent is allowed to evaporate and then one more coat of the release agent is applied to make sure that the entire die surface is covered properly. In fact after evaporation, a thin layer of Teflon is left as residue on the surface, which prevents adhesion of epoxy over the die surface and ensures easy removal of cured product from the die.

2.5.2 Making of the preform

A preform is an uncured form of the product. This is prepared by stacking layers of prepregs cut in right shape and fiber orientation. The thickness of preform is slightly larger than the thickness of cured product. The prepregs are cut in size using a Template 1 (Fig.2.8 a). The entire surface of the flanged cone is not developable, although the cone portion can be developed easily. Template 1 (Fig. 2.8 a) is designed such that its central portion makes the cone and outside portion is used as the flange. The outside portion is cut on the radial lines shown in the figure for ease of developing of flange surface. The prepregs cut with the help of template, are stacked over the die layer by layer by removing backing films (BOPP) to obtain the preform of the product. It should be ensured that no part of BOPP film is left on the preform otherwise it would act as a crack in the product. The number of layers of the laminates required depends on the desired thickness of the product. Usually to obtain 1 mm thickness of product, 8 prepreg layers are needed. In the present work, 26 layers of Template1 shaped prepregs (Fig.2.8 a) are used which ensures 3.2 mm. thickness of cone. To make flange of 4mm thickness another Template 2 (Fig. 2.8 b) is designed to cut appropriate annular shape. Ten layers of prepreg are used for flanged portion in addition to layers cut with the help of Template1. Templates are kept oversized to compensate for the cutting and finishing of the product.

2.5.3 Curing of the preform

The die-set with preform is loaded in a hydraulic press having heated platens. A hydraulic press having heated platen, used in present work is shown in Fig.2.9. Then temperature controller is set at 120-125° C; it takes half an hour for the system to reach this temperature (control panel of the press is shown in Fig.2.10). During this heating phase no pressure is applied on the die-set. Preform is allowed to cure at this temperature for one hour. Then pressure is applied on the preform, which should be 4-7 bar. It has been found that at 5-bar pressure best quality of product is achieved.

Temperature is now increased to 145-150° C and the preform is cured at this temperature for 2 hours. The die is then allowed to cool while the pressure is maintained. The temperature and pressure cycle for curing of preform are shown in Fig.2.11 a and Fig2.11.b respectively. Technical specifications of the hydraulic press are given in Table.2.4.

Table 2.4: specifications of the hydraulic press

Capacity	25 Ton
Platen size	460x460 (mm)
Piston area	182.41 cm^2
Temperature range	Room temperature to 400° C
Heating	Electric heating(both platen is controlled by separate temperature controller)

2.5.4 Release of the product

After the curing of the preform, die and punch are separated and product is taken out. Care should be taken when taking out the product; the surface finish of the die and punch should not be destroyed. Product is then trimmed to the required size on the cutter (preferably on diamond cutter). Then product is smoothened by a waterproof emery paper; a waterproof emery paper does not leave scratches on the product.

2.6 FRP PRODUCTS

Three pieces of FRP flanged cone are made. These are named as SDP-1, SDP-2 and SDP-3, where SDP stands for Steel Die Products. Products are shown in Fig.2.12.

A good quality FRP product means no lamination in product, optimum fiber-to-resin ratio, fewer voids content, good wetting of the fibers and very small variation in obtained product dimensions and designed dimension. A good composite should have fiber volume fraction in between 40-55 %. The high void content significantly effects the mechanical properties because it means lower fatigue resistance, greater susceptibility to water penetration and scatter in strength properties. A good composite should have less than 1%, whereas a average composite can have upto 5%. Several test methods adopted for determining quality of the FRP products are:

(i) Burn test for finding volume fraction of fibers and void.

(ii) Coin test to check the product delaminating

(iii) Optical Microscopy for microstructure

(iv) Dimensions of the product

2.6.1 Burn test for FRP products

In burn test volume fraction of fiber, matrix and void are calculated. Burn-tests are conducted for Flange and Cone part of the product. As the cone part is developable, but flange is not, thus tailoring of prepregs was done in making of the flange part thus it becomes necessary to conduct burn tests for flange and cone part separately to analyze the effect of tailoring. Procedure for burn test is as following.

(i) A specimen of 10×10 mm is cut from the FRP product.

(ii) Specimen is cleaned and dried, then weights the specimen in air and water (it gives the sp. gravity of the composite material).

(iii) The specimen is placed in a furnace, temperature is increased gradually to 1000° C. Specimen is burnt at 1000° C for 15 minutes, and residue is weighted (in this step, the entire epoxy gets burnt out and weight of fiber content is determined).

Formulae used:

Formulas used to find out volume fraction of the fibers, matrix and void content in the composite material [Agarwal and Broutman, 1990] are :

Density of the composite material, ρ_c is given as;

$$\rho_c = \frac{m_a . \rho_w}{m_a - m_w}$$

where,

ρ_w = density of the water (gm/cc)

m_a = weight of the specimen in air (gm)

and m_w = weight of the specimen in water (gm)

Weight-fraction of the fiber (w_f) and matrix or epoxy (w_m) is given as,

$$Wf = \frac{mf}{ma}$$

$$Wm = \frac{mm}{ma}$$

where,

m_f = weight of fiber (weight of the specimen after burning) (in gm)

and m_m = weight of the matrix (in gm)

$= m_a - m_f$

Volume fraction of the fibers (V_f), matrix (V_m) and void content (V_v) is given as,

$$Vf = \frac{\rho c}{\rho f} wf$$

$$Vm = \frac{\rho c}{\rho m} wm$$

$$Vv = \frac{\rho ct - \rho ce}{\rho ct}$$

where,

ρ_f = density of the fibers (gm/cc)

= 2.54 gm/cc for glass fibers

ρ_m = density of the matrix material (gm/cc)

= 1.15 gm/cc for epoxy

ρ_{ce} = experimental density of composite material (in gm/cc)

and ρ_{ct} = theoretical density of the composite material

$$\rho ct = \frac{1}{\frac{wf}{\rho f} + \frac{wm}{\rho m}}$$

Table 2.5 Burn-Test Data

Specimen name.	Part Name	Volume Fraction of (in %)	
		Fiber	Void
1. SDP*-2	Cone	63.7	4.3
	Flange	60.3	2.0
2. SDP*-3	Cone	46.5	2.4
	Flange	48.5	2.1

* SDP = Mild Steel Die Product

As discussed earlier, for good quality of the composite product, the void content should be as minimum as possible. The burn test data for product SDP-1 are not given because a layer of prepreg backing film (BOPP) was left accidentally, while preparing the preform. Consequently, it worked like an interlaminar crack and few plies were separated out. In later products, enough care was taken in removing the BOPP film.

The volume fraction of fibers in product SDP-2 is on higher side than desirable volume fraction of 40-55 % because too high pressure was applied during the curing so epoxy was squeezed out in excess. While making SDP-3, corrective action was taken thus the volume fraction comes out to be desirable. And as found out from the burn-test, void content in all products is below 5%, which indicates that quality of the product is fairly good.

2.6.2 Coin test

It is a very simple test to have an idea of delamination in the FRP product. In coin test, a coin is struck on the FRP product, and sound is observed. If sound is like that of metal (high frequency sound) it indicates that the quality of the product is good. Otherwise there may be delamination in the product or high void content. Sound in all three products is of high frequency just like that of metal, which indicates that there is no delamination.

2.6.3 Optical Microscopy

Optical microscopic study of the product is done to study of wetting characteristics and fiber matrix interaction. Study is conducted on the ZIESS Optical Microscope, West Germany. Specimens are cut in 10x10-mm size. Specimens are first smoothened on edge side having cross-section of fibers by waterproof emery paper. Then specimens are polished by a powder, 0.3-MICRON ALPHA ALUMINA, manufactured by BUEHLER MICROPOLISH, USA. Figure 2.13 to Fig. 2.14 shows the optical microscopic study of the products. Cone and Flange parts are studied separately to know the effect of tailoring on flange. Figures show that flow of matrix around the fibers is good. There appears to be no gap left between matrix and fibers. The distribution of the fibers is quite good.. This wetting ensures strong interfacial bonding thus better load transfer from matrix to fibers.

2.6.4 Dimensions of the product

The critical portion of this product is cone portion, its internal dimension and angle. Placing the product on the steel cone checks this and fit was found to be quite good. The thickness of cone and flange depends on the pressure applied during the curing. Table 2.6 shown the thickness for the various products. The dimensions of product SDP-1 are not given because a layer prepreg backing film (BOPP) was not removed while preparing the preform. Consequently, it worked like an interlaminar crack and a few plies were taken out. The wall thicknesses of SDP-2 are on smaller side because too high pressure was applied during curing. As a result, the volume of the product is much higher than the desired volume fraction of 40-55 % (given in Table 2.5). While making the SDP-3 corrective action was taken and thickness were closer to the designed values.

Table 2.6 Designed and Obtained wall thicknesses of the product

Part name	Designed dimension (in mm)	Obtained dimension (in mm)		
		SDP*-1	SDP-2	SDP-3
Cone (thickness)	3.2	_	2.4-2.6	3.0-3.1
Flange (thickness)	4.0	_	2.5-2.7	3.6-3.8

* For SDP-1 data is not included because a backing film (BOPP) was left in product therefore some layers were removed.

In matching die-set (made of fairly rigid modulus like metals and their alloy), there is compression constraint and it is inherent problem. This problem is more dominant in complex products as pressure at all point can not be uniform thus thickness in product variation occurs. Thus, it is realized that for complex FRP products, fabrication techniques based on a single die may be more appropriate. This concept is exploited in the pressure bagging technique in which all portion of FRP product are

uniformly compressed by the high pressure nitrogen gas. However, the pressure bagging technique is quite expensive as the entire bag is rejected after the fabrication of one product. It is worthwhile to explore alternative methods which are based on a single die but are inexpensive enough for their acceptability to make down to the earth products. One possible way may be explored where the matching upper die is made of flexible material such as silicon rubber. If the height of the flexible upper die is reasonably high, the pressure on the FRP preform will be distributed more uniformly when compared with matching die-set are made of a rigid materials. RTM (resin transfer molding) is another effective technique for complicated FRP products. In this technique as discussed earlier in Chapter 1, the cavity between two dies is filled with a preform made of dry fabric or fibers and epoxy is filled at high pressure like an injection molding.

2.7 CONCLUDING REMARKS

A component of FRP composite is made using a die set of mild steel. Prepregs are cut in right shape using templates and then stacked over die. The preform is cured under a temperature and pressure cycle. After curing die set is opened and FRP product is released. FRP product is cut using diamond cutter in desired shape and smoothened using waterproof emery paper. Tests are performed on the products to evaluate the quality of the products; tests show that quality of the products is fairly good. Limitations of the matching die-set made of rigid material for manufacturing of complex products is discussed and possible alternative methods are discussed. Same component is made using die set made of MCP, a low melting point alloy, then comparison is made between the products and tooling technique. The procedure to make die set of low temperature alloy, and subsequently its use in making FRP product is illustrated in Chapter 3.

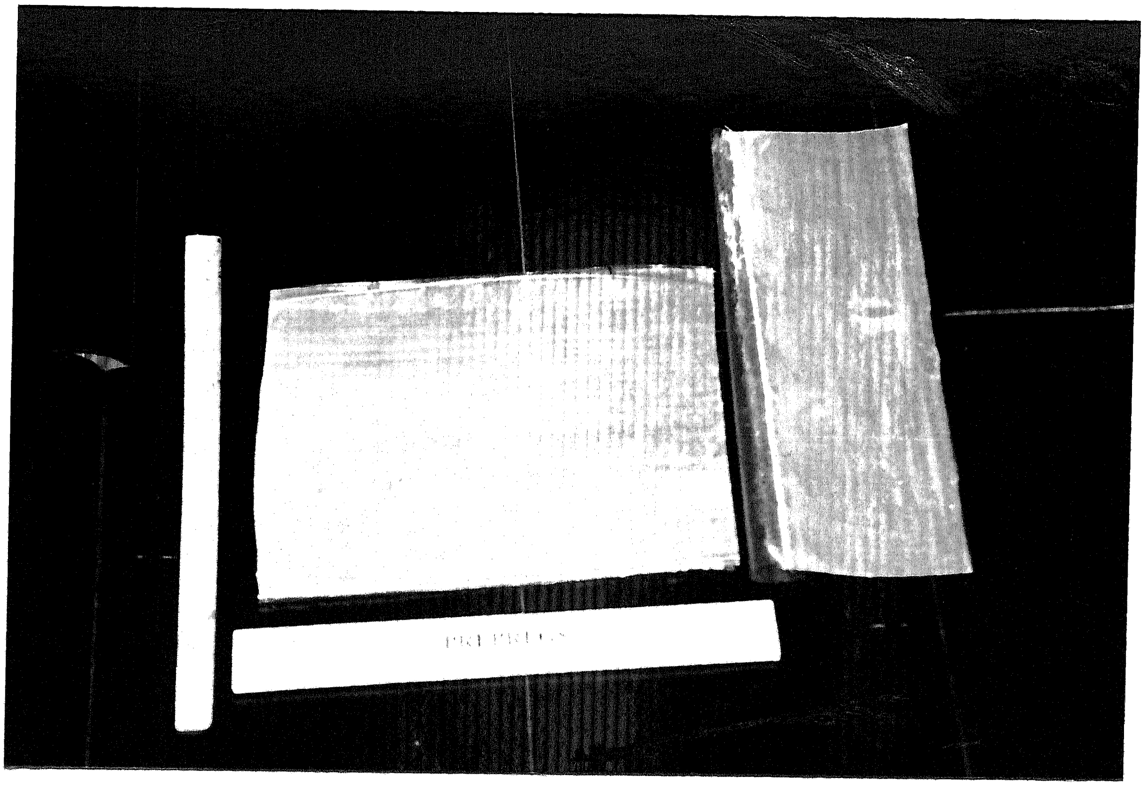

Figure 2.1: Glass Fabric Prepregs

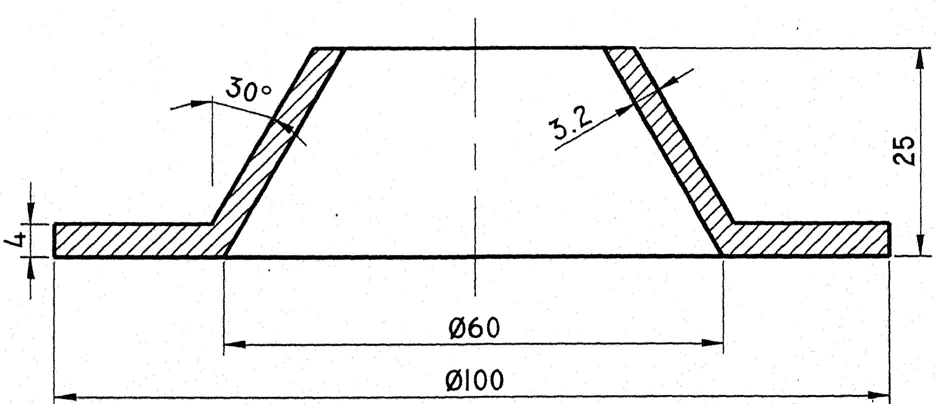

Figure 2.2: Detailed Drawing of Flanged Cone

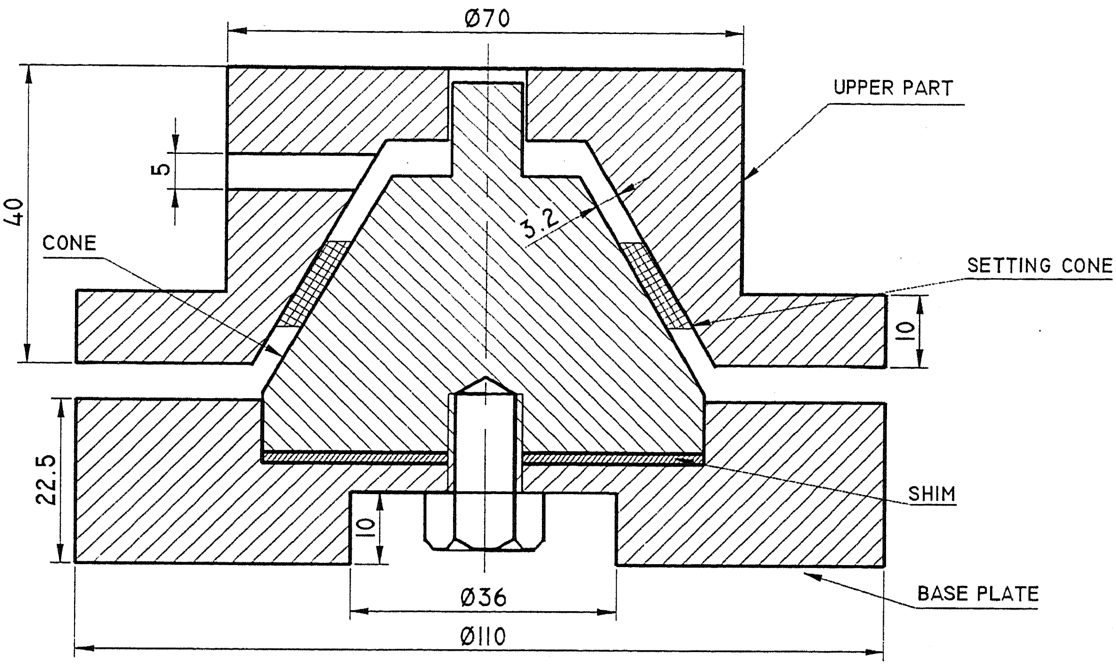

Figure 2.3.a: Assembly of Die-Set and Setting Cone

Figure 2.3.b: Different parts of the Die-set

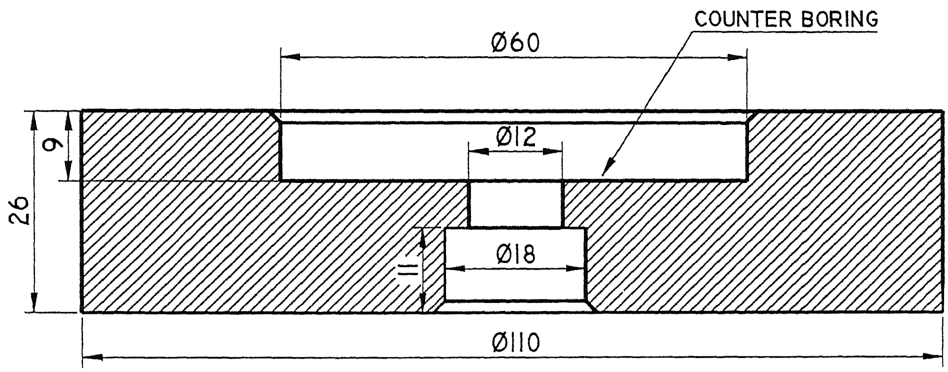

Figure 2.4: Base Plate

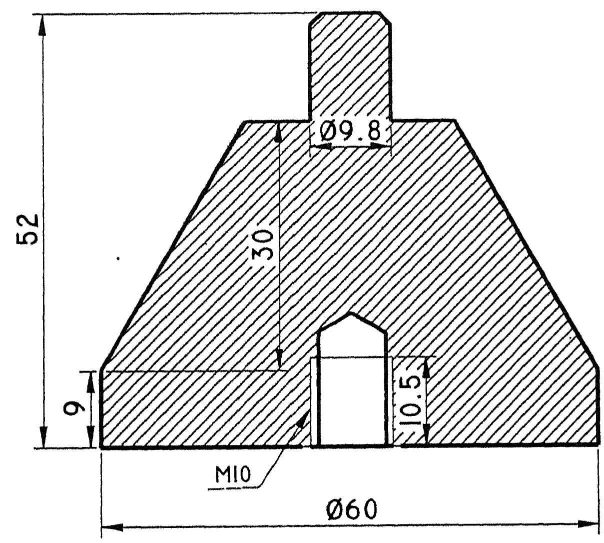

Fig.2.5: Cone

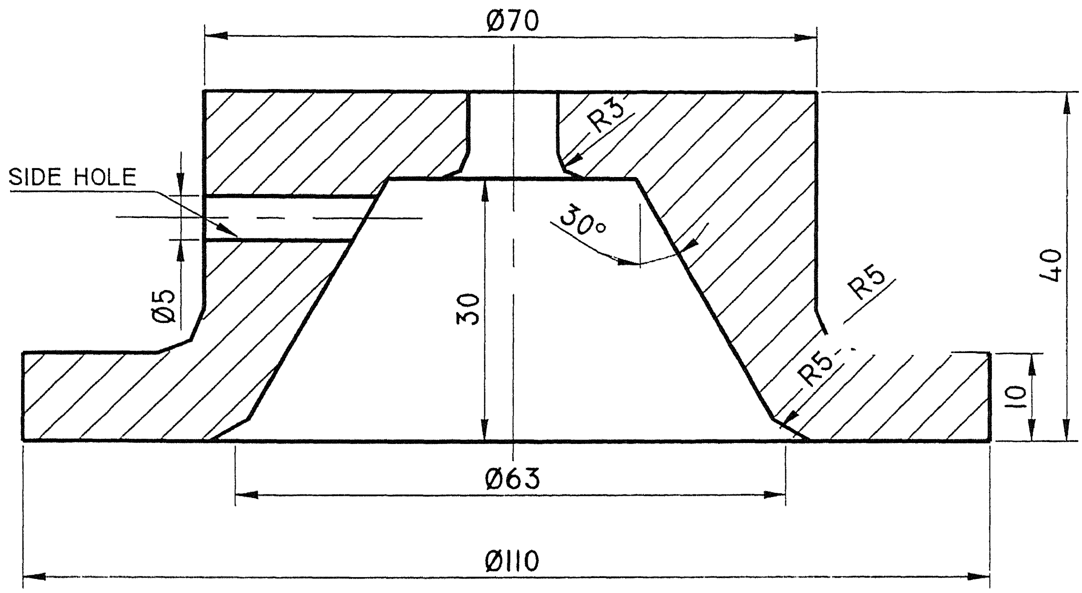

Figure 2.6: Upper Die

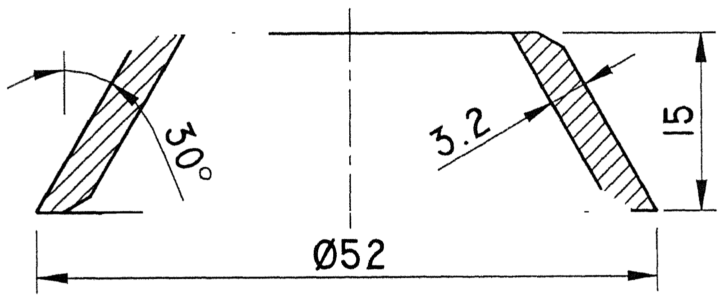

Fig.2.7 Setting Cone

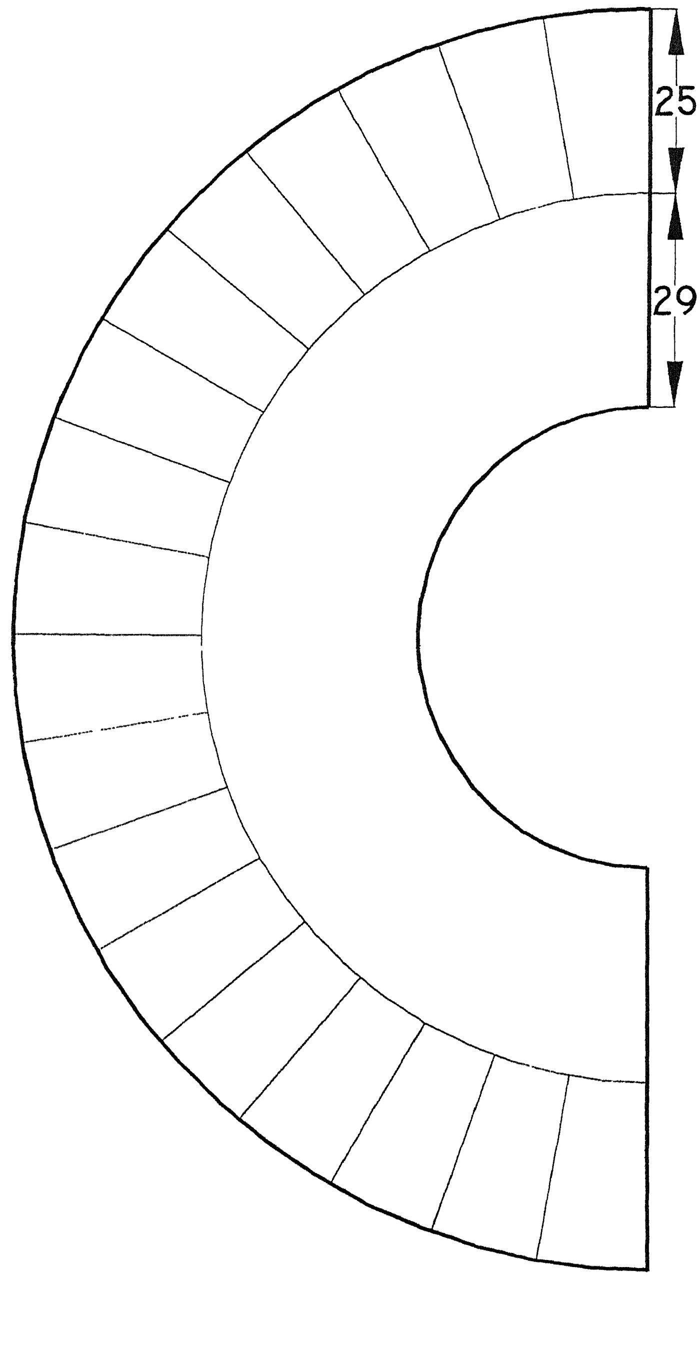

Figure 2.8 (a): Template-1

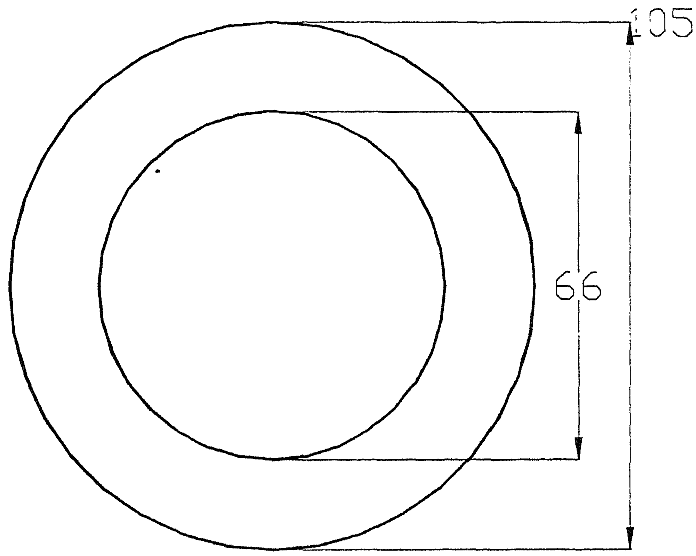

Figure 2.8 (b): Template-2

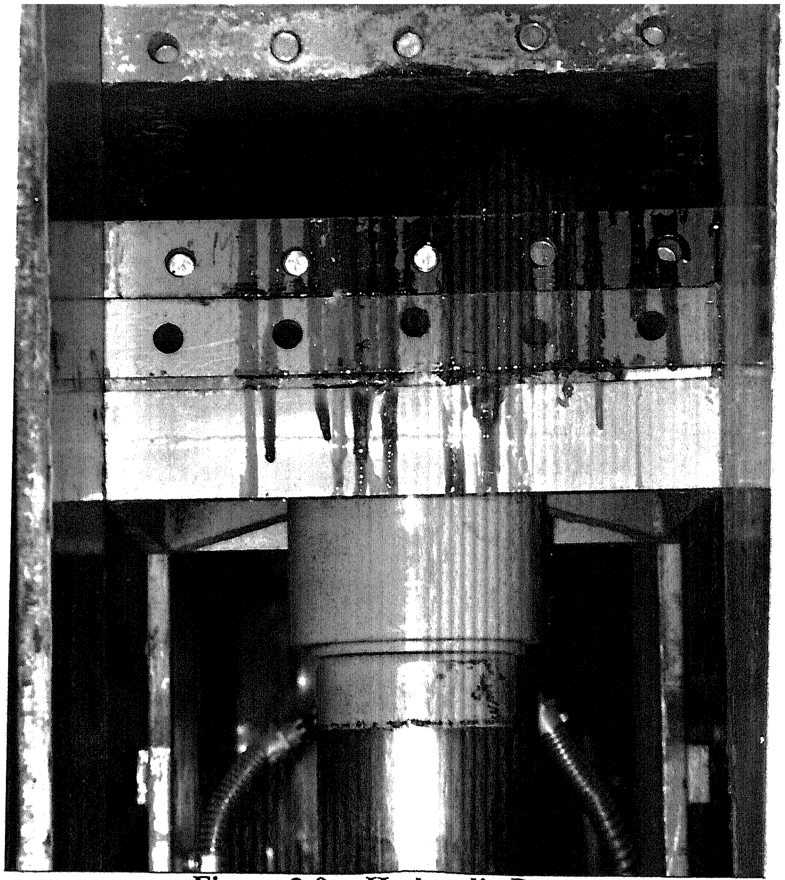

Figure 2.9 : Hydraulic Press

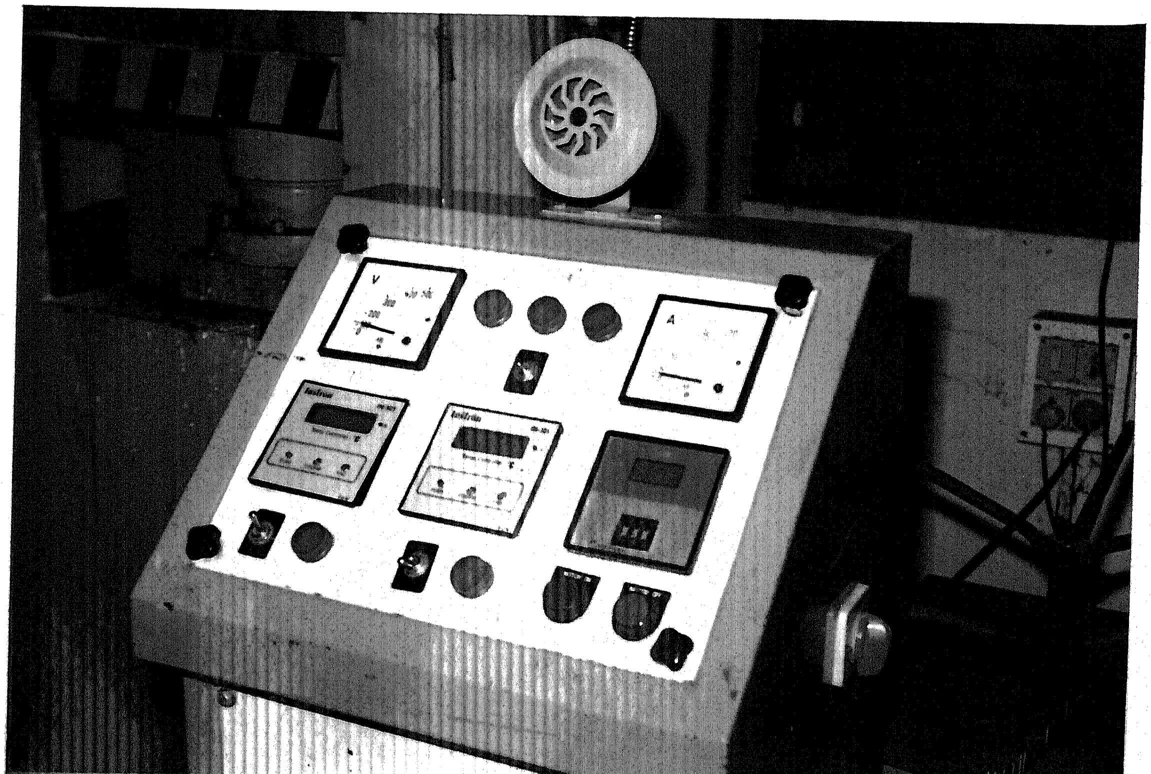

Figure 2.10: Control Panel of the Hydraulic Press

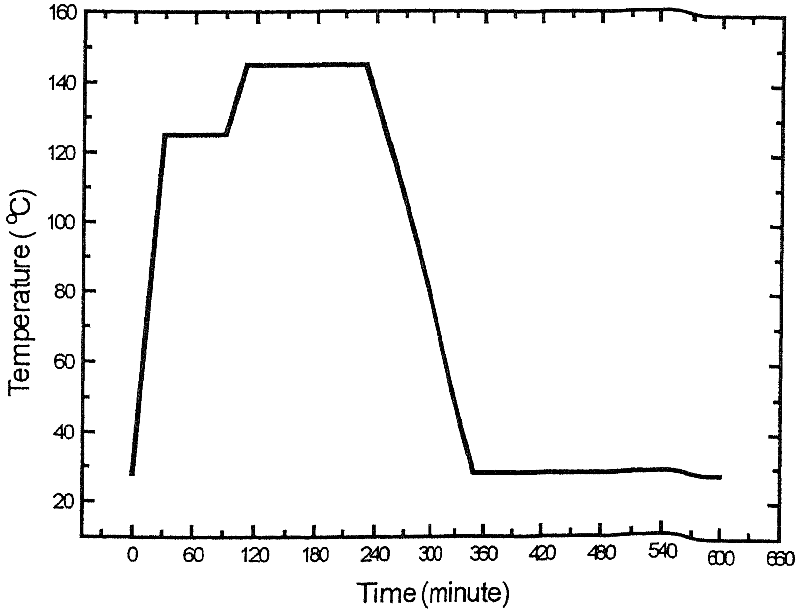

Figure 2.11 a: Temperature-Time Curve

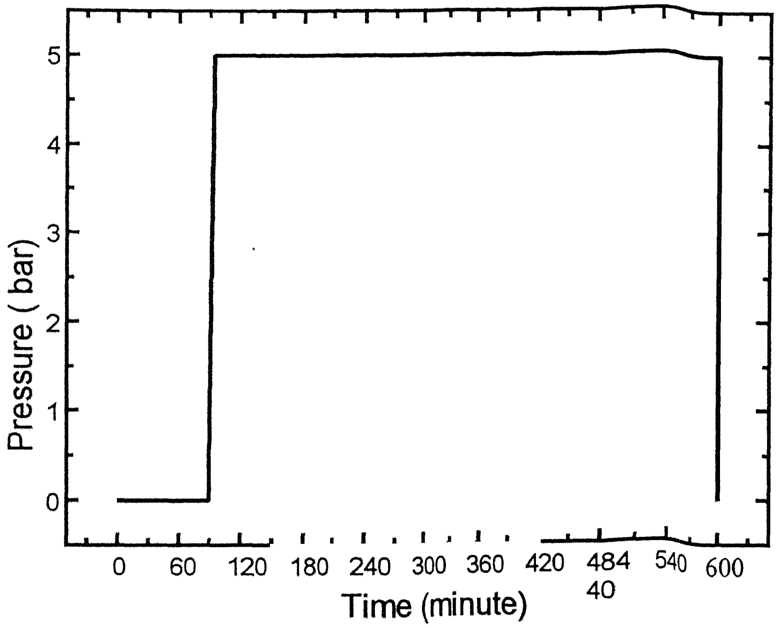

Figure 2.11 b: Pressure-Time curve

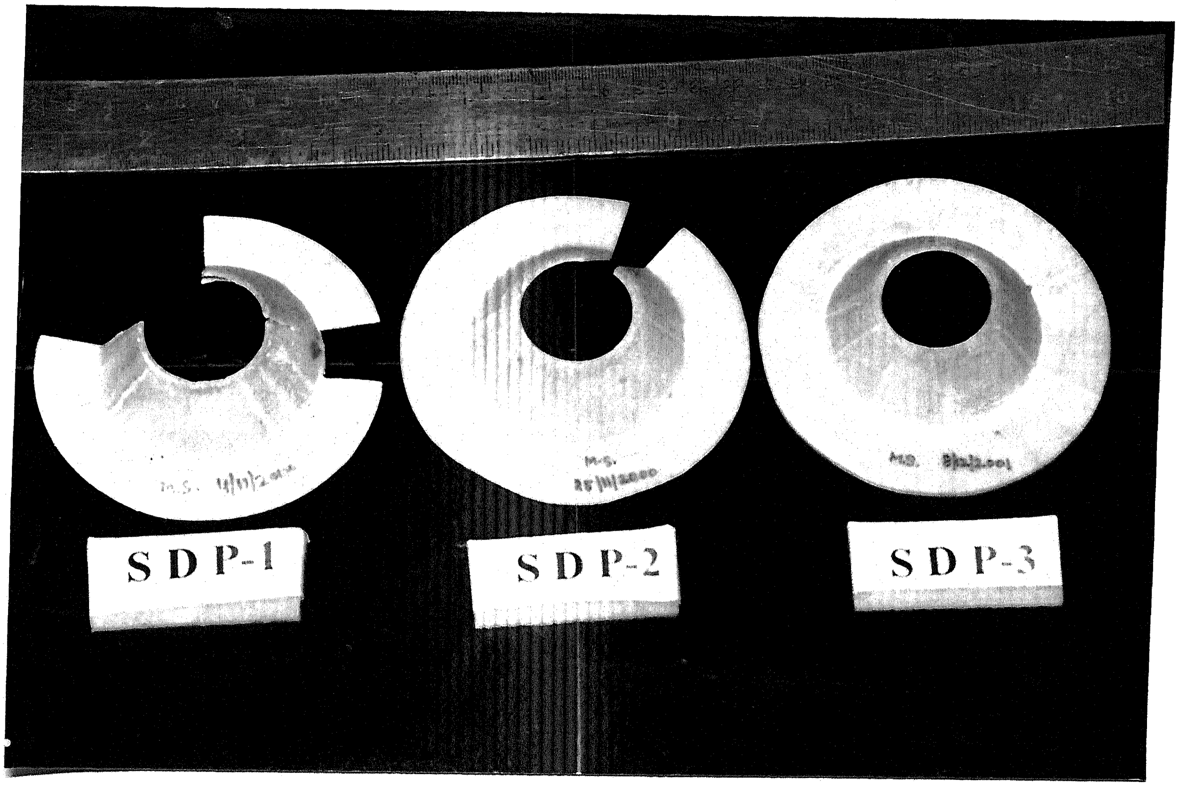

Figure 2.11: FRP products(cut portions indicates the parts cut for making burn-test specimen)

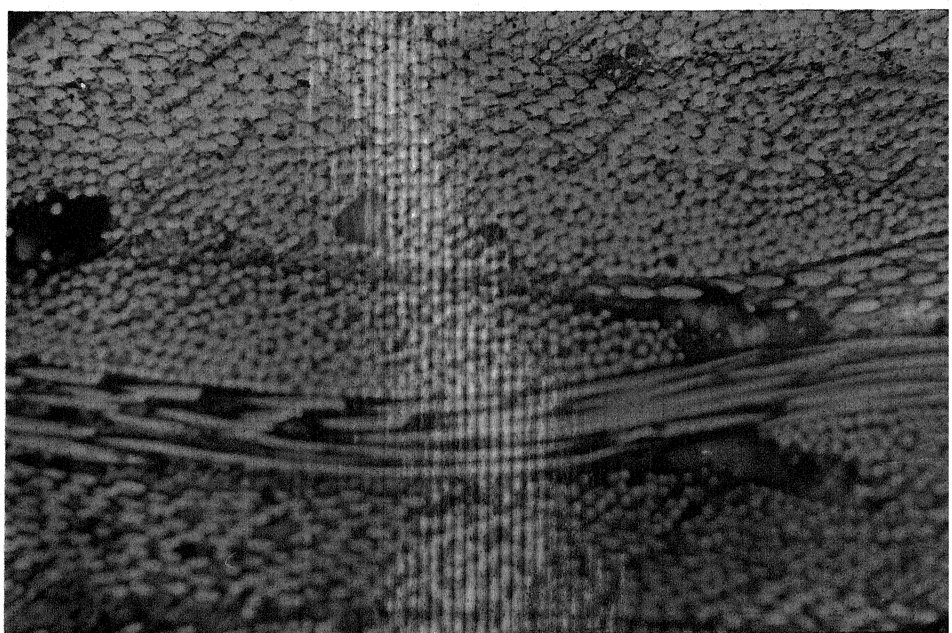

Figure 2.13 Optical microscopy of the SDP-2 (flange)

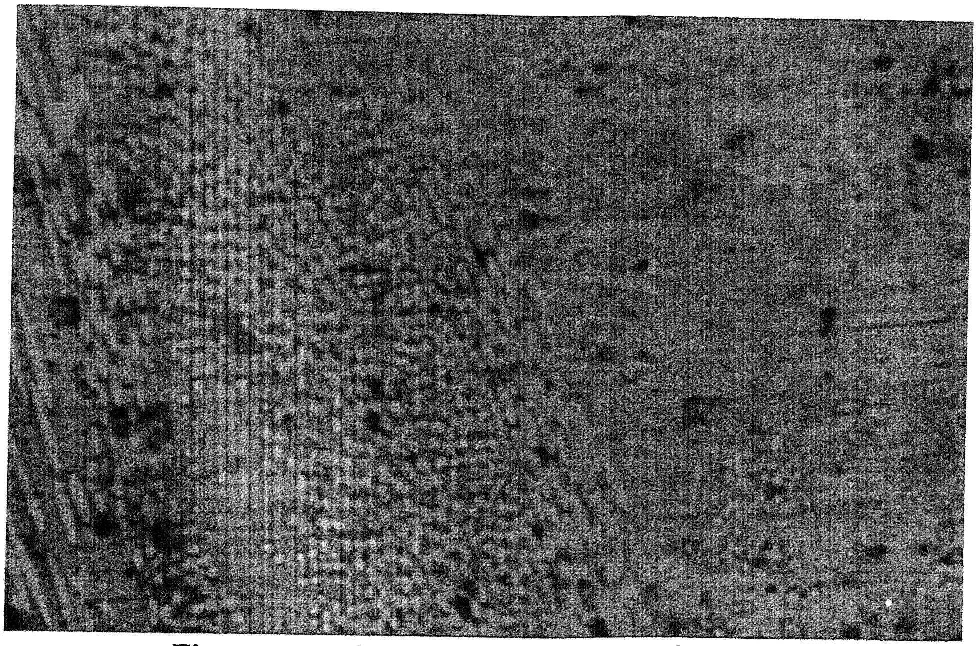

Figure 2.14: Optical microscopy for SDP-2 (cone)

CHAPTER 3

MANUFACTURING OF FRP PRODUCTS USING RAPID TOOLING

3.1 INTRODUCTION

In this chapter, making of FRP products using new technique of Rapid Tooling is described. As defined in the first chapter, Rapid tooling (RT) is a collection of technologies and processes that delivers components in a fraction of time as compared to conventional tooling method. Out of several techniques of rapid tooling Low Temperature Alloy technique is employed for making die-sets in present work. In this technique, suitable alloy with low melting point (MP) is poured around the pattern to prepare two halves of the die-set. A FRP product (flanged cone) fabricated using conventional tooling, is described in Chapter 2. The same product is made using rapid tooling in the present chapter. Product quality tests are performed on products, and a comparison is made between FRP product (flanged cone) made by the Conventional Tooling and the Rapid Tooling to predict the acceptability of the new technique.

3.2 LOW TEMPERATURE ALLOY

3.2.1 Low Temperature Alloy

Low temperature alloy is an alloy having a substantially lower melting point as compared to conventional metals or alloy like steel, aluminum, brass, and titanium. Low temperature alloy is employed for making the die-set from the master pattern. A die-set is prepared by pouring the molten metal on both side of the pattern.

Development of low temperature alloys played an important role in opening new routes to rapid tooling. Various low temperature alloys, in the range of melting point 45°-350°, are available in the market. In present work, a low temperature alloy of melting point 200° C, developed by Mineral & Chemical Product (MCP), Geneva Switzerland is selected for making die-sets. It is designated as MCP 200, where MCP refers the company name and numeric digit denotes melting point of the alloy. It is selected because curing temperature does not go beyond the 170° C in entire production cycle of FRP products.

MCP 200 alloy is composed principally of Bismuth, Tin, Indium and Zinc. Company does not disclose the exact composition. Indium is used to obtain an extremely low melting point. Bismuth is added because it has a rare property of expanding 3.3 % by volume when it solidifies. Since most metal shrinks on solidification, mixing Bismuth appropriately with other metals creates alloy which do not shrink much on solidification. The low temperature means ease of handling of process of die making. The alloys are stable metals as they can be repeatedly remelted and used again. These alloys do not stick much to many materials and therefore these are found to be suitable materials for making die-sets. The properties of MCP 200 are given in Table 3.1[MCP-manual].

Table 3.1: Properties of MCP 200 Alloy

Density (gm/cc)	7.27
Latent Heat of Fusion (J/kg)	71200
Specific Heat, Solid (J/kg K)	239
Specific Heat, Liquid (J/kg K)	272
Thermal Conductivity (W/m K)	61.0
Electrical Resistivity (μ Ohm-cm)	11.2
Tensile yield Stress, 0.2 % set (MPa)	42.6-48.4
% Elongation	30-32.5
Tensile Strength (MPa)	54.7-64.2
% Reduction in Area	77.5-80

Compressive yield Stress (MPa)	50.8-51.8
Brinell Hardness(2mm ball, 4 kg load)	21.5-24.5

3.2.2 Methodology for making Die-Set using Rapid Tooling

Methodology for making rapid tooling die-set is illustrated in Fig.3.1. First the pattern is cleaned and degreased properly with acetone and placed inside the casting frame in proper position. The pattern is fixed on the base plate with the help of modeling clay. Fixing of pattern is necessary to prevent the disturbance of the pattern from its position when molten MCP-200 is poured. When the alloy melts, it is poured over the pattern and is allowed to solidify (Fig.3.1 c). In this way, first part of the die-set is prepared. Now the die is removed from the casting frame and is placed again in casting frame in inverted position (Fig.3.1 d). The molten alloy is poured over the inverted die (Fig.3.1 e). It is allowed to solidify. In this way complete die-set is prepared.

When the die is completely solidified, die-set is taken out from the casting frame. Before separation of both parts, two or three holes of ϕ 4-6 mm are drilled through both half of the die-set and dowels are inserted to avoid the possibility of the misalignment. Now both parts are separated and pattern is removed. Pattern comes out easily because MCP-200 does not stick much with other materials. After removing the pattern; outside face (which is not on the parting line of the die-set) of both parts are machined to remove about 1-5 mm thickness so that during the curing of the preform, entire pressure acts on preform and upper and lower part do not touch each other. Occasionally, bubble pits may be found on the surface of the die-set. If the bubble pits are large, pouring a few drops of the molten MCP-200 fills them and surface is smoothened by a fine emery paper. For small pit mixture of epoxy and aluminum powder is used for filling. Now die-set is ready for making FRP products.

3.3 MAKING OF RT DIE-SET FOR FLANGED CONE

In Chapter 2 one FRP product, a flanged cone, is made using die-set made from conventional tooling. Same product is made and discussed in the present chapter, using a die-set made of the low temperature alloy tooling.

3.3.1 Preparation of the Pattern

Sufficient care should be taken during the preparation of the pattern. While designing a pattern, allowance should be taken for trimming and finishing of the FRP product; the pattern should be designed in such a way that removal of the pattern from the die-set should be easy. Various materials like mild steel, aluminum, plaster of Paris and aluminum mixed with epoxy etc. can be used for making the pattern.

A pattern is designed, for the Flanged cone product as illustrated in Fig.2.1. Various details of the pattern are shown in Fig 3.2. Mild steel is chosen as the material for pattern. Mild steel has good strength and is easy to machine. It is experienced that mild steel is released easily from the surface of the die-set made of MCP-200 alloy. Flange diameter of pattern is kept as 120 mm to account for radial allowance of 10 mm for trimming and finishing of the product. The height of pattern is taken as 31 mm by taking an allowance of 6mm for trimming of conical part of the product. Thickness of the flange and cone part is taken as 4mm and 3.2 mm respectively. A cap (as shown in Fig.3.2) at the top of the pattern is suitably designed because the top part can not be kept open during the pouring of molten alloy. This cap serves two purpose, first it does not allow the molten alloy to fall inside the cone while pouring the alloy for first half of the die, second it saves pattern from deformation while taking out the pattern from the die-set because pattern is taken out by striking at the top (as shown in Fig.3.4).

3.3.2 Preparation of the Casting Frame

A casting frame is common in all casting process. It can be made of wood or metal. In the present work, a casting frame made of mild steel is used. The casting

frame is of split type to facilitate the removal of the die-set. A split type of casting frame is shown in Fig.3.3. The casting frame is made slightly bigger than the pattern but not too big to economize on the alloy MCP-200 which is a costly material.

3.3.3 Preparation of the Base Plate

A base plate is used to support the pattern and casting frame. A base plate should be flat, smooth and horizontal. It is to be noted that when the molten alloy is poured inside the casting frame, the liquid acquires horizontal plane at the surface and it solidifies as horizontal plane. If the base plate is not horizontal, there will be a wedge between the die surface and the heated platen of the press during curing of product. Consequently, the pressure will not be uniform and the heat transfer will be poor. The surface of the base plate should be smooth, as any irregularity present on the base plate may reflect in the die surface.

3.3.4 Casting of the Die-Set

The pattern, the base plate and the casting frame are cleaned properly with the acetone to remove any grease or oil present. The pattern is temporary fixed over the horizontal base plate with the molding clay. Now casting frame is placed and it is also temporary fixed with the molding clay. MCP-200 is melted inside a stainless steel pot placed on the electric heater. A low temperature alloy melting tank is also available in Mechanical Engineering Department of I.I.T Kanpur, which is mainly suited for mass production. Now the molten alloy is poured in the casting frame with the help of a funnel to ensure smooth pouring of molten alloy. A small Borosil glass funnel is used in present work, as it does not stick with MCP-200. The Borosil glass has low thermal capacity and therefore the melted alloy does not solidify in the funnel. After the pouring, alloy solidifies which takes about 15 minutes. After solidification the first half (part-1) of the die-set is ready.

The first half of the die-set is removed from the casting frame and is placed again in the casting frame in inverted position. Then a glass fabric reinforced teflon sheet is placed all over the die except where the pattern part is. The molten alloy is poured over it; the teflon sheet prevents molten alloy to fuse with the solidified first half of the die. Molten alloy is allowed to solidify. After solidification, die-set is taken out from the casting frame. As discussed earlier, before separating both parts, two or three holes are drilled through both halves of the die-set and dowel pins are inserted to minimize the misalignment of the die-set during curing of the FRP products. Both parts are separated out and pattern is removed. Outside faces of both parts of the die-set are machined to make them flat. The inside face (which is on the parting line of the die-set) upper half (part-1) of the die –set is machined to avoid the direct surface contact between upper and lower parts of the die-set (Fig.3.5). This makes sure that there is full pressure on the component at all instant during the curing process and force is not transferred from one part to other part of the die directly. Now, the die-set is ready for making FRP flanged cone. A completed die-set alongwith pattern is shown in Fig.3.6.

3.4 MAKING OF FRP PRODUCT USING RT DIE-SET

The methodology to make FRP products from the prepregs is discussed in Chapter 2 using a mild steel die-set. The same methodology is used to make FRP parts using the RT die-set. Three FRP flanged cones are made.

3.5 PRODUCT

Three products are made using rapid-tooling die set (Fig.3.7). These are named as RTP-1, RTP-2 and RTP-3, where RTP stands for Rapid Tooling Product. Several test as discussed in the chapter 2, are conducted to predict the quality of the products.

3.5.1 Burn test

In Chapter 2, burn test procedure and formulas are described. Same procedure will be used for burn-test of FRP flanged cone made using rapid tooling. Burn tests will be conducted for flange and cone parts separately. Flange parts are made by doing tailoring of the prepregs so it is necessary to analyze the effect of tailoring on the quality of the product.

Table 3.2 Burn-Test data

Specimen Name	Part Name	Volume Fraction of (in %)	
		Fiber	Void
1. RTP*-2	Cone	50.7	0.6
	Flange	52.0	2.2
2. RTP*-3	Cone	49.1	3.4
	Flange	51.1	2.9

* RTP= Rapid Tooling Product

As discussed in earlier, for a good quality composite product, fiber volume ratio should be in between 40 and 55 % and void fraction should be below 5%. Burn-test data for product, RTP-1 is not included because a BOPP film was left in this product also just like product SDP-1, as they were first products to make and all variables could not be managed. In product RTP-2, enough care was taken for removing BOPP films, Volume fraction of the fibers in RTP-2 is in between 40-55 %, and void content is below 5 % ,

this shows that the quality of the product RTP-2 is fairly good. Data shows that there is no effect of the tailoring on the flange because in flange void and fibers content are within limit. In product RTP-3, the product quality is fairly good as volume fraction of fibers and voids is in desirable limit.

3.5.2 Coin test

There is high frequency sound in product RTP-1 and RTP-2 when the surface is tapped with a metallic coin. Both flange and cone parts gives metallic sound. This shows that there is no delamination in the product and the quality of the product is fairly good.

3.5.3 Optical Microscopy

Specimens are cut in 10X10 mm size. Then specimen are smoothened and polished. Then study is conducted under the ZIESS optical microscope. Figures from 3.8 to 3.9 shows that there is uniform distribution of the fibers and fairly good wetting of the fibers.

3.5.4 Dimensions of the Product

As discussed earlier, the critical portion of this product is cone portion, and its dimension are checked by placing it on the cone of die set of MCP and fit is found to be quite good. The wall thicknesses of the product depend on the pressure applied during the curing. Table 3.3 shows the thicknesses of products. The thicknesses of the product RTP-2 and RTP-3 are on smaller side because high pressure was applied accidentally. The pressure gauge of hydraulic press, which is being used, has high least count that is equal to 5 bar, which is much larger than the pressure to be applied, thus for applying pressure approximation is made. Thus for better results, a hydraulic press with smaller least count should be used.

Table 3.3 Designed and Obtained wall thicknesses of the product

Part name	Designed dimension (in mm)	Obtained dimension (in mm)		
		RTP*-1	RTP-2	RTP-3
Cone (thickness)	3.2	_	2.8-3.0	3.1 –3.2
Flange (thickness)	4.0	_	3.1-3.4	3.4 –3.6

* For RTP-1 data is not included because a backing film (BOPP) was left in product therefore some layers were removed.

3.6 COMPARISON IN SDP AND RTP TO PREDICT THE ACCEPATABILITY OF THE NEW TECHNIQUE

Comparison in FRP products made by conventional and rapid tooling is made on the basis of quality tests conducted on them. There is no delamination in both types of products because coin test gives metallic sound in both types of product. It is clear from the burn-test of the RTP that the volume fraction of voids and fibers are in desirable limits. And when burn-test data of RTP is compared with SDP, it shows that quality of the RTP's is not poor than SDP. Microscopic structure of RTP indicates that flow of matrix around the fibers is good; there appears to be no gap left between matrix and fibers and the distribution of the fibers is quite good. There is good wetting of the fibers with epoxy in RTP, which ensures better load transfer from the matrix to fibers.

3.7 CONCLUDING REMARKS

A new technique for manufacturing FRP products is illustrated. In this technique, a matching die-set of low temperature alloy is made by casting process.

Then FRP flanged cones are made using this die-set. Then to know the acceptability of this new, products made by this technique are compared with products made by conventional tooling. On comparison, it is found that the quality of the products made by this new technique is very much similar to the quality of the products made by conventional tooling. But rapid tooling has several advantages over the conventional tooling so the new technique for making FRP products is fully acceptable for making the FRP products. But this technique is not very effective, where the wall thickness of the product is critical dimension, in most of the daily life products wall thickness is not of much importance thus this technique is fully acceptable for making daily life FRP products.

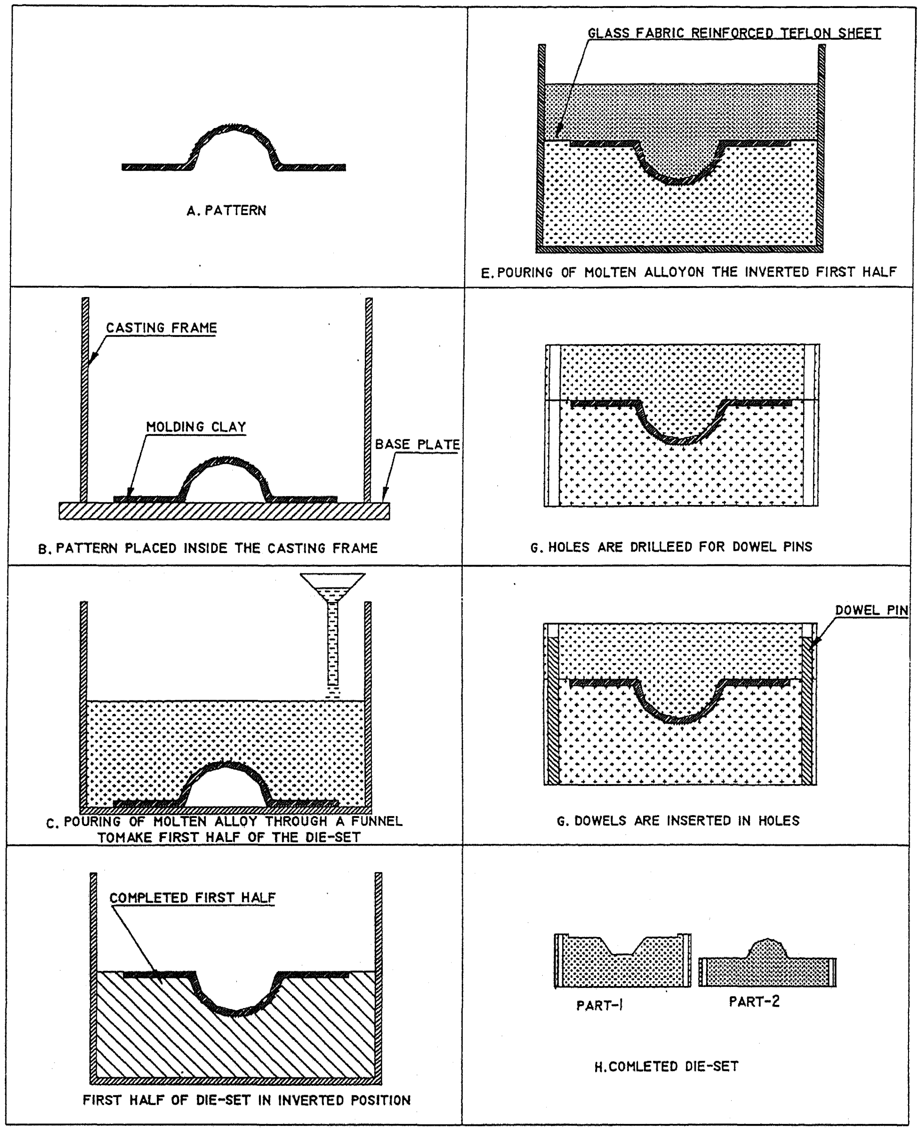

Figure 3.1 Methodology for making rapid tooling die-set

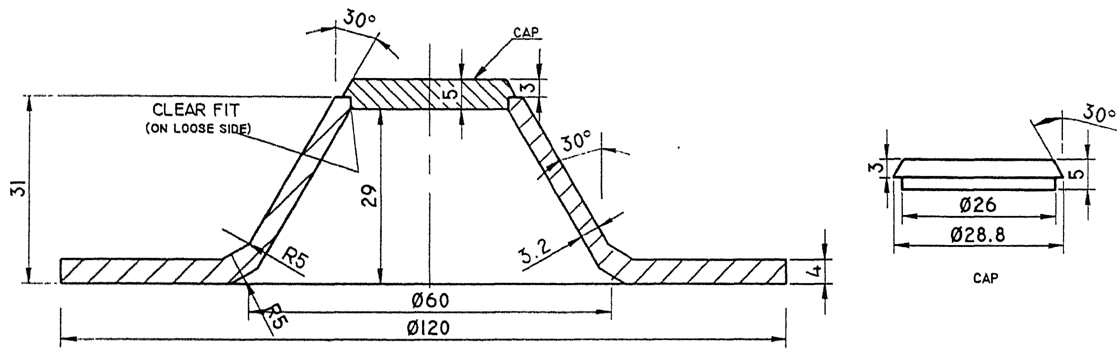

Figure 3.2: Pattern for Flanged Cone

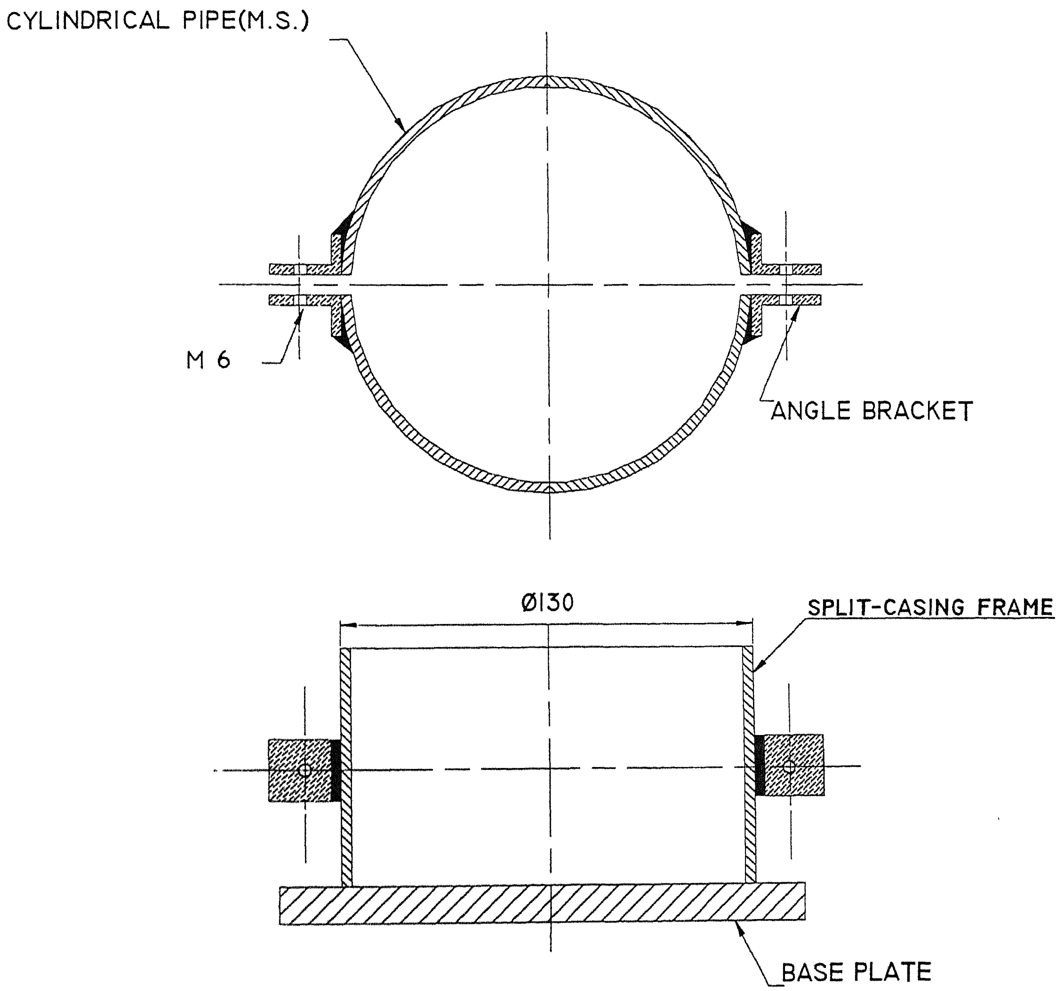

Figure 3.3: Split Type Casting Frame

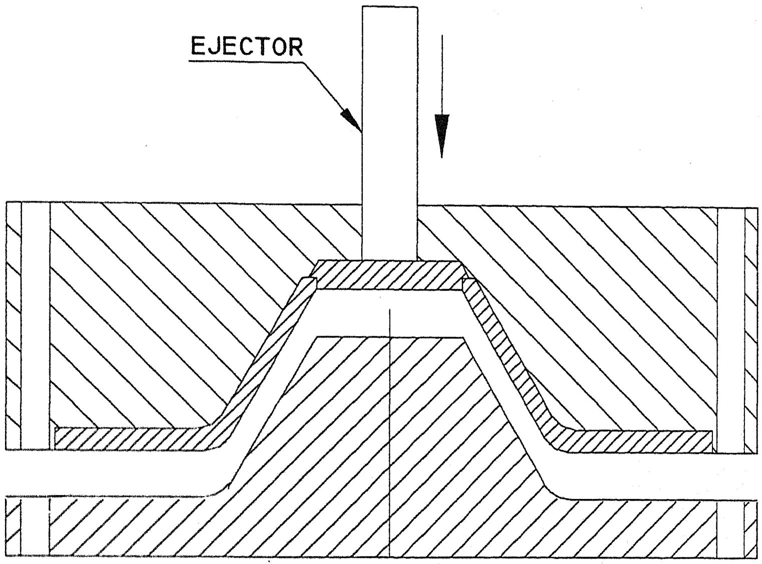

Figure 3.4 Pattern is taken out using ejector

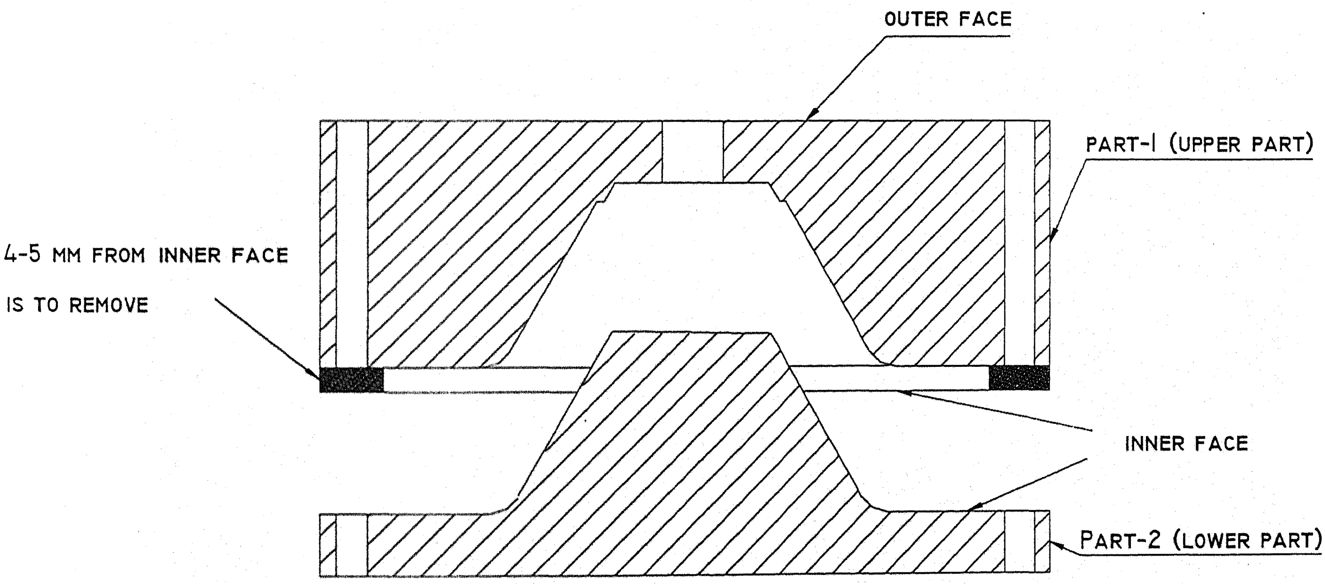

Figure 3.5 Machining of the Inner Face of the Part-1

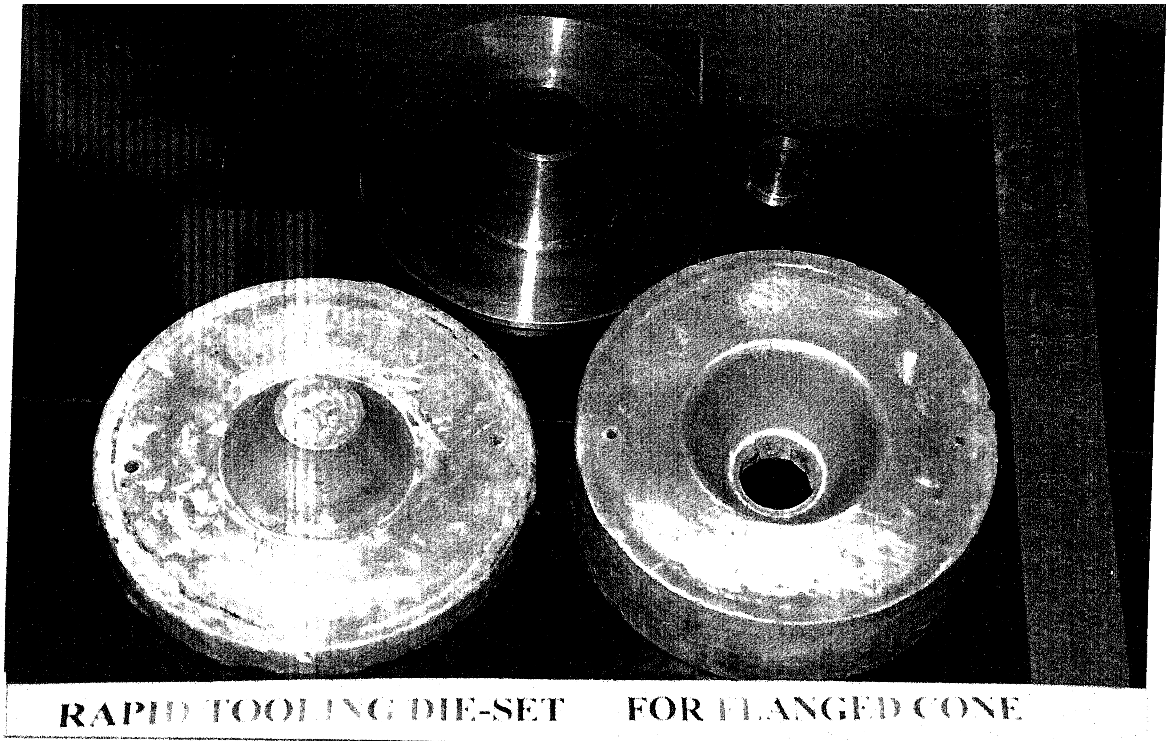

Figure 3.6 Die-set with Pattern

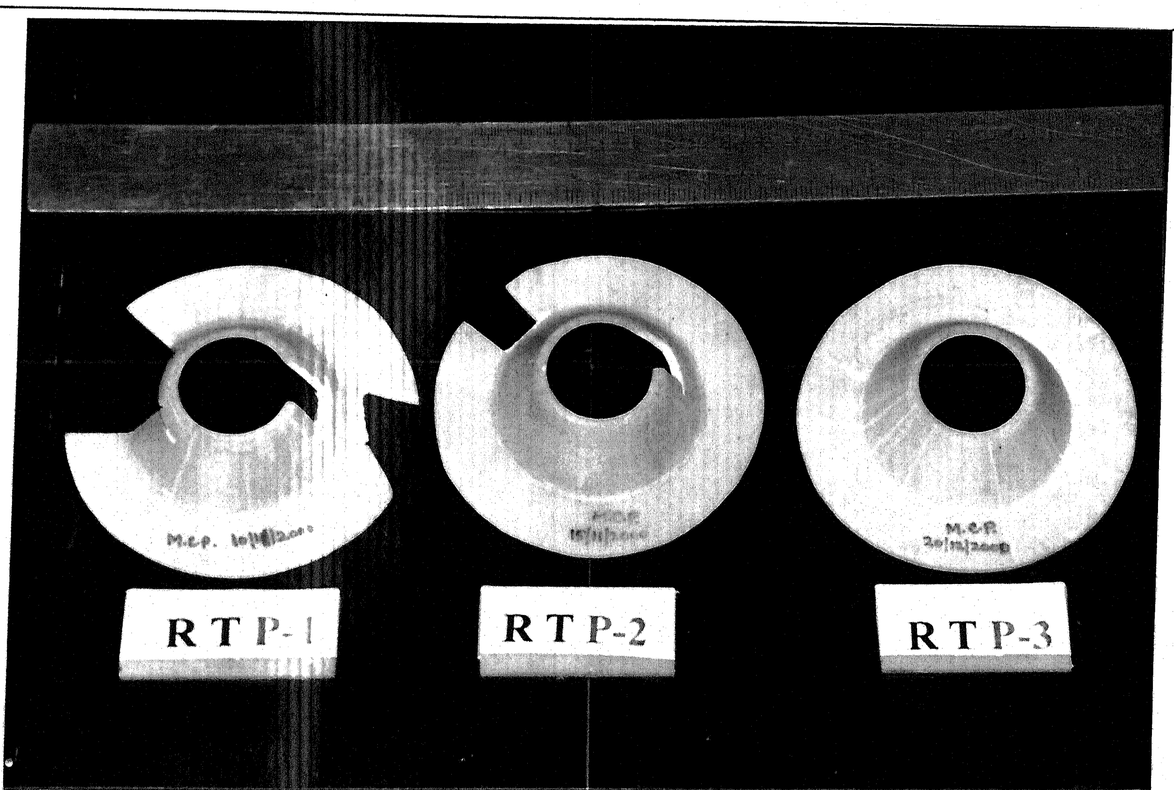

Figure 3.7 Rapid Tooling Products (cut portions indicate the parts used for making specimens for burn test and optical microscopy)

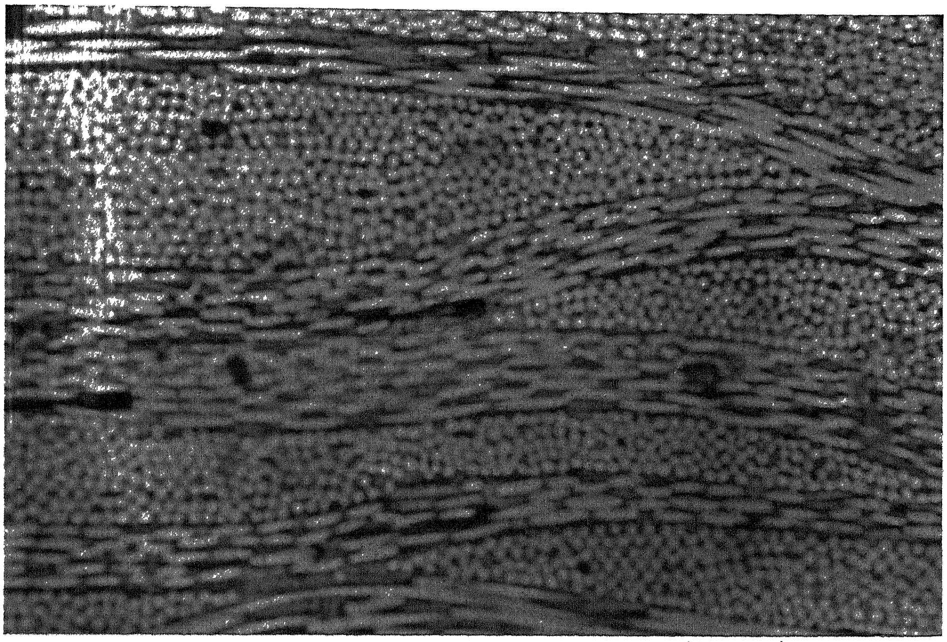

Figure 3.8 Optical microscopy of RTP-2 (Flange)

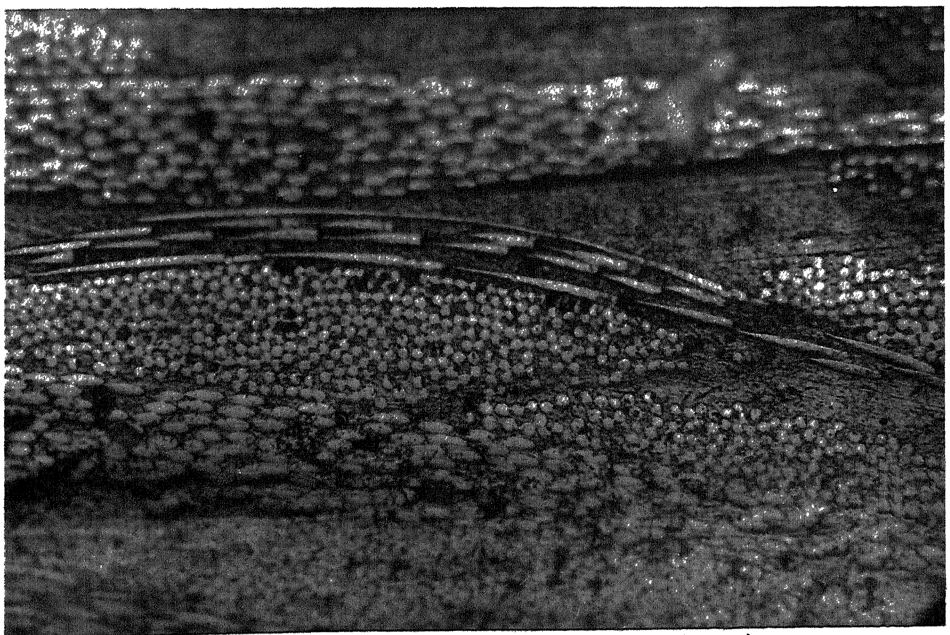

Figure 3.9 Optical microscopy of RTP-2 (cone)

CHAPTER 4

MAKING OF A RAPID TOOLING DIE-SET USING PARTING LINE CONCEPT

4.1 INTRODUCTION

The methodology for making die-sets using a low temperature alloy rapid tooling is explained in Section 3.2.2, in which a pattern is placed on base plate and metal is poured over pattern. In that methodology, surface of the base plate reflects the parting line of the die-set. But this methodology is not suitable in cases where surface of base plate does not reflect the parting line of the die as in case of a single piece cylinder pattern (Fig.4.1). In the die-set for a cylinder, parting line should be corresponding to mid plane of the cylinder and this mid plane can never lie on the surface of base plate if this pattern is a single piece. In present chapter, an attempt has been made to develop a concept for casting of the die-set from the patterns for which the parting line does not lie on the base plate. This concept will be called as "Parting Line Concept" (PL concept) in the present work. Low temperature alloy die-sets for a cylinder and a table tennis bat are made using PL concept.

4.2 PARTING LINE CONCEPT FOR MAKING RT DIE-SET

A pattern is inserted in a parting plate by cutting central portion of the plate appropriately. The parting plate is supported on the three supporting bolts (as shown in Fig.4.2). A system is designed to adjust the parting plate so that it becomes horizontal. The parting plate is required to be horizontal because, when the liquid metal is poured, it solidifies with the top surface on a horizontal plane. For the adjustment, the parting plate is supported on three bolts which are configured to be in L-shape to facilitates independent rotation of the parting plate along x and y axes. Each bolt is specially

designed for this purpose. The top end of the bolt is inserted into the parting plate through a tapped hole. To the bottom portion of the bolt, a groove is made so that the bolt does not move up and down when it is rotated. The methodology for making die-set using parting line concept is illustrated in Fig 4.3. The molten alloy is poured in the molding box upto the height of lower face of the parting plate. After solidification of the alloy, the parting plate and supporting bolts are taken out and the half of the die is prepared. Since the lower surface of the plate reflects the parting line of the die-set, the pattern should be inserted in the parting plate properly. Before the liquid alloy is poured to make second half of the die, parting plate is removed and a thin sheet of glass fiber reinforced teflon is placed over the first half except where the pattern is. This is done to avoid the fusion of the liquid alloy with the solidified one. As shown in Fig.4.3.e, the molten alloy is poured. The second half of die is ready when the molten alloy solidifies. And before separating both halves, two or three holes are drilled for dowel pins. Then both parts of the die-set are separated and pattern is taken out.

Using parting line concept for making die-set, three types of product are made. A hollow cylinder, a cylinder with a metallic core and a table tennis bat are made. Fabrication process for these products is explained in following sections.

4.3 MAKING OF THE FRP HOLLOW CYLINDER

4.3.1 Product definition

First product made using parting line concept, is a hollow cylinder of external diameter 20 mm, wall thickness 2.0 mm, and length of 35 mm.. A detail drawing of the product is given in Fig.4.4.a.

4.3.2 Preparation of the Pattern and the Base Plate

Sufficient care should be taken in the preparation of the pattern; trimming and finishing allowance should be considered. The pattern should be designed

Fig.4.3, die-set for the cylinder is made. A die-set prepared for making FRP cylinder is shown in Fig.4.6.

4.3.4 Manufacturing of the FRP Cylinder

The die-set is cleaned properly with acetone to remove oil and grease from the surface of the die. Then two layers of SAFERELEASE # 30 are applied on the die surface. Prepregs are cut in right shape and orientation. A metallic core is prepared, external diameter of the core is equal to internal diameter of the product and length equal to the length of the pattern. Core is coated with two layers of the safe release so that it can be taken out easily from the product. A preform of the product is prepared by stacking prepregs layer by layers on the core, 20 layers of the prepregs are used to get thickness of 2.5 mm. Then the preform is placed in cavity of the die-set. The preform is loaded in a press with heated platen, and subjected to a pressure and temperature cycle for curing as illustrated in Fig.2.8. After curing of the product, die-set is separated and product is taken out. Now metallic core is removed from the FRP product. Cylinder is now cut in right shape on a diamond cutter and finished by a water proof emery paper. Three FRP products are made, a hollow cylinder and two cylinders with metallic core.

4.4 MAKING OF THE FRP TABLE TENNIS BAT

4.4.1 Product Definition

A table tennis bat is chosen as FRP product. The detailed drawing of the product is shown in the Fig.4.7. The circumference of the face of table tennis bat is cubic spline curve. Thickness of the face of table tennis bat is 5 mm. The handle of the bat has rectangular cross-section, thickness of the handle is 23mm and is constant, but width is decreased linearly from 21 to 15 mm through the 85 mm length of the handle.

4.4.2 Preparation of the Pattern and the Base Plate

A pattern is designed for the table tennis bat, is shown in Fig.4.8. Mild steel is chosen as the pattern material. Trimming and finishing allowance for edge of the face of bat is taken as 4 mm and circumference of the face is cubic spline. Thickness of the face and handle of the bat is taken as 5 and 23 mm respectively, no trimming allowance is taken in these dimensions because these parts makes the surface of the pattern and allowance is considered for edges only. Considering an allowance of 2.5 mm for width, width of the handle of pattern is taken 26 mm. An allowance of 5 mm is taken for trimming of the length of handle, thus length of the handle of pattern is chosen as 90 mm. A parting plate to support the pattern is designed as shown in Fig4.8.

A wooden casting frame is used because size of the die-set is quite large and a wooden casting frame is easy to assemble and disassemble thus die-set can be easily taken out. A base plate similar to the one used in making die-set for cylinder, is used here except the size of the base plate is large to accumulate the large sized die-set of table tennis bat.

4.4.3 Making of Die-set for table tennis bat

Pattern is placed in the designed parting plate, and supported on the. Using the same methodology as discussed in Section 4.3.3, the die-set is prepared. A die-set prepared for table tennis bat, is shown in Fig.4.9.

4.4.4 Manufacturing of the FRP product

Die-set is cleaned and a safe release agent is applied on surfaces of the die. Prepregs are cut into desired shape for face and handle separately. Then a preform of the product is prepared by stacking prepregs on the lower die layer by layer. Then complete assembly is now loaded in the press where preform is cured by applying a curing cycle.

After curing of the preform, product is taken out and it is trimmed in desired shape on a diamond cutter, and finished using a waterproof emery paper.

4.5 PRODUCTS

4.5.1 Hollow Cylinder

Three hollow FRP cylinders are made using parting line concept (Fig.4.10). One is a hollow cylinder; and two cylinders are having metallic core.

Burn Test

In Chapter 2, burn test procedure and formulas were discussed same procedure will be used for burn-test of the FRP cylinder also.

Table 4.1 Burn-Test data

S.No.	Product Name	Volume fraction (in %) of	
		Fibers	Void
1.	Hollow Cylinder	45.5	1.9

From burn-test for the cylinder, volume fraction of void and fibers comes out to be 1.9 % and 45.5% respectively. As volume fraction of the fibers lies in 40-55; and void content is much below the 5%; thus the quality of the product is fairly good;

Coin test

Coin test of the FRP cylinder shows that there is neither delamination in product nor the high void content.

Optical Microscopy

A Specimen is cut from the FRP hollow cylinder and polished well on the face side having cross-section of the fibers. And it is studied under the Geiss optical microscope. Optical Microscopic study of the product shows that there is good wetting of fibers by epoxy matrix and there is uniform distribution of the fibers (as shown in Fig.4.11).

Dimension of the product

The critical dimensions of the FRP cylinder are its outer diameter and thickness. Table 4.2 shows the obtained dimension of the FRP cylinder alongwith the designed dimensions..

Table 4.2 Designed and Obtained dimensions of the product

S.No.	Part Name	Designed dimension (in mm)	Product dimensions (in mm)
1.	Thickness	2.0	2.0
2.	Outer diameter	20.0	19.0-20.0

Table 4.2 shows that obtained dimensions are very close to the designed dimensions.

4.5.2 Table Tennis Bat

A FRP table tennis is made, as shown in Fig.4.12. Various quality tests as illustrated earlier, are performed on the product to predict its quality

Burn Test

Burn test is conducted on the face and handle part of the table tennis bat separately because both parts have different geometrical features. Specimens are cut from face and handle parts. Then specimens are cleaned properly, and using same procedure as discussed earlier in Section 2.6.1 following results are obtained:

Table 4.3 Burn-test data

Part Name	Volume fraction (in %) of	
	Fibers	Void
1. Face	42.2	2.5
2. Handle	39.2	6.5

Coin test

Face of the table tennis bat gives high frequency metallic sound when a metallic coin is struck on the surface of the product. But the sound in handle part is not of high frequency this indicates the presence of large voids in handle as clear from the burn test data also. The handle part is more complex as compared to face, its manufacturing is more difficult. Prepregs of handle shaped are cut and stacked over each other since the size of these prepregs is small, these prepregs slide over each other when pressure is applied for curing. The quality of the face of table tennis bat is satisfactory. The handle with very high thickness has relatively layer void content. Further development work is required to improve the quality of handle. In fact, the handle can be made hollow by inserting a core. These prepregs are placed at their position using a rod or a knife manually which disturb the orientation and position of the prepregs; and air bubbles also go inside the perform of the handle.

Dimensions of the product

Table 4.4 Designed and Obtained dimensions of the product

S.No	Part Name	Designed dimensions (in mm)	Obtained dimensions (in mm)
1.	Face (thickness)	5.0	4 1-4.3
2.	Handle (thickness)	23.0	21.4-21.6

As clear from the Table 4.5, product dimensions are near to the designed dimensions.

4.6 CONCLUDING REMARKS

A new method or concept has been developed for making the rapid tooling die-set for the single piece and complex shaped pattern. In this method, a pattern is suspended on the bolts and molten alloy is filled upto the height of the pattern where we want the parting line of the die-set. Die-sets for a cylinder and a table tennis bat are made using this concept and these die-sets were subsequently used for making the FRP products. Tests conducted on these FRP products show that the quality of the products is fairly good.

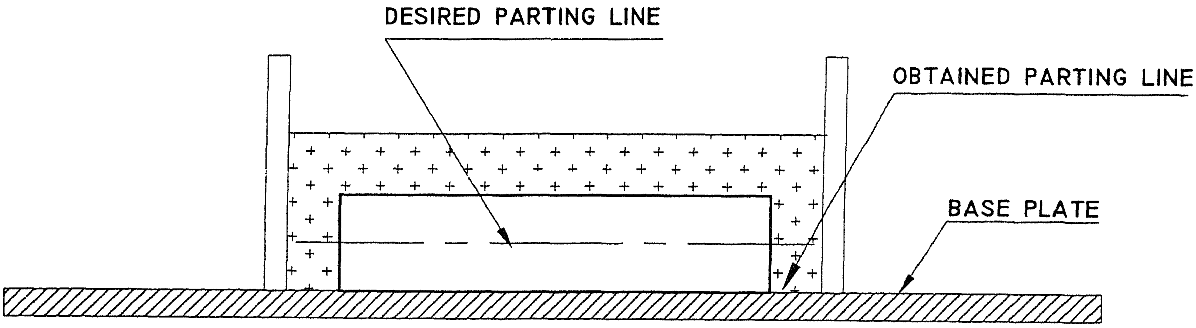

Figure 4.1 Parting line for a single piece cylindrical pattern

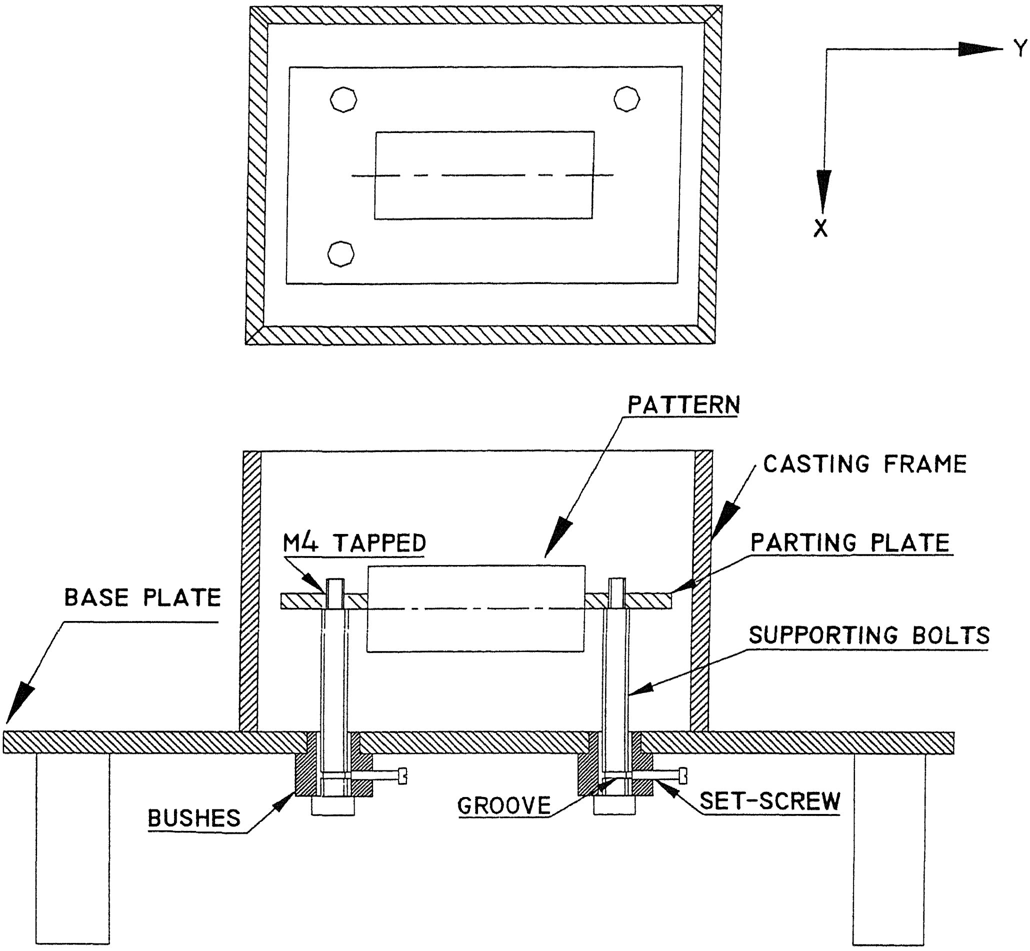

Figure 4.2 Pattern inserted in PL plate and supported on bolts

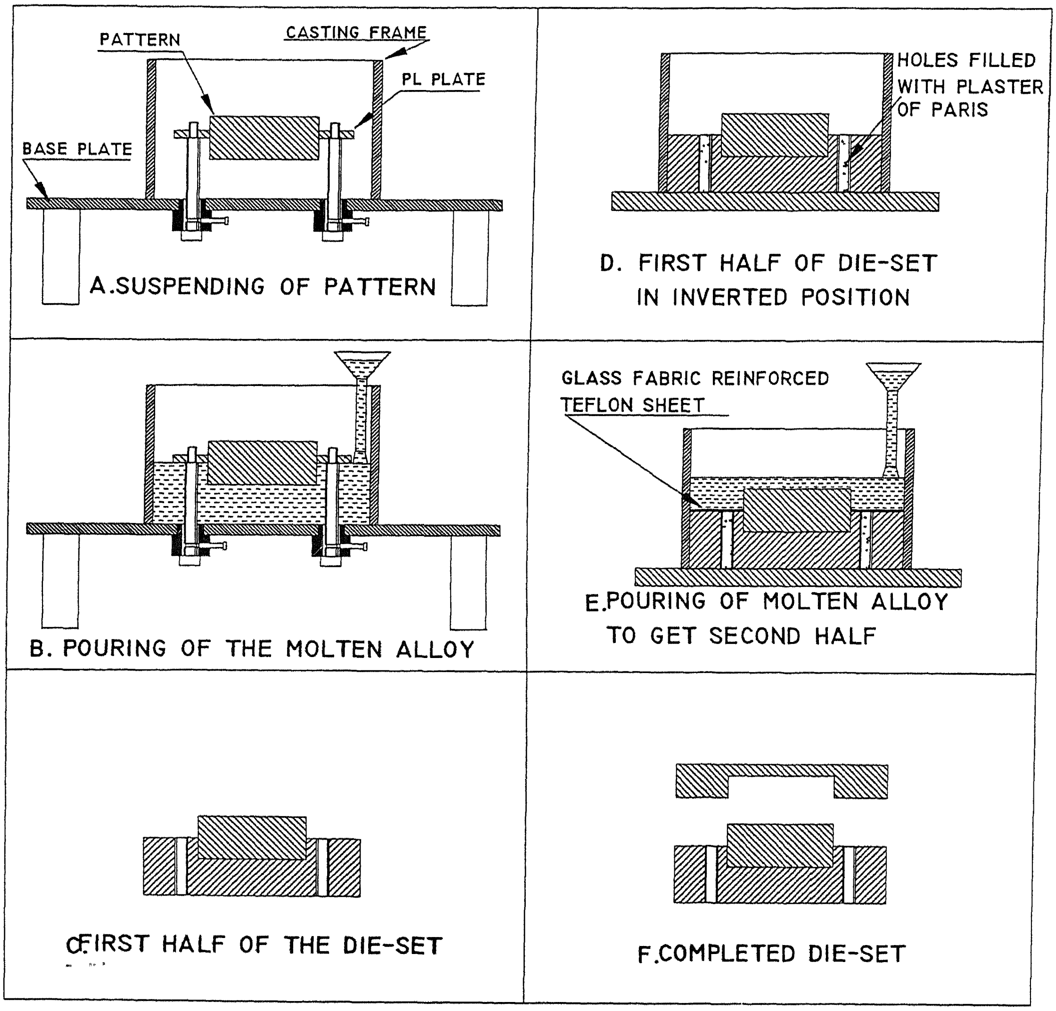

Figure 4.3 Methodology for making RT die-set using Parting line concept

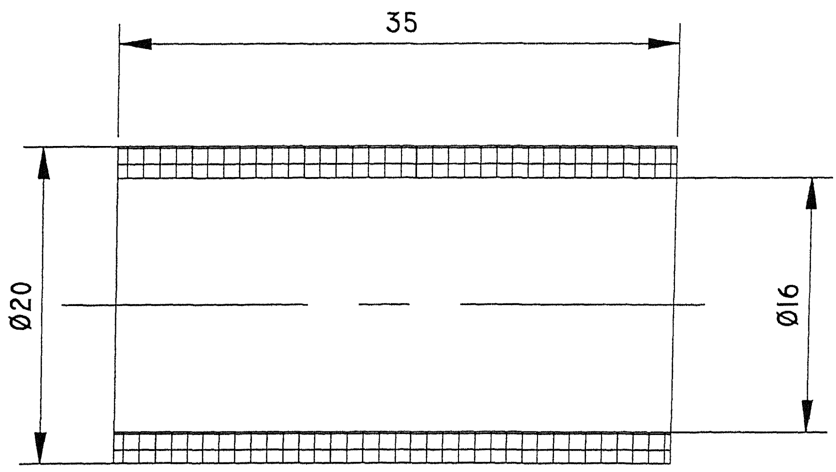

Figure 4.4.a Hollow cylinder

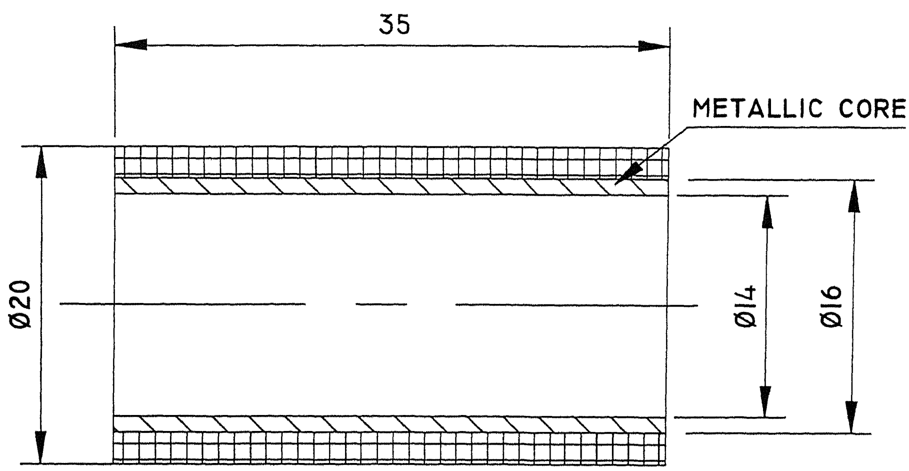

Figure 4.4.b Hollow cylinder with metallic core

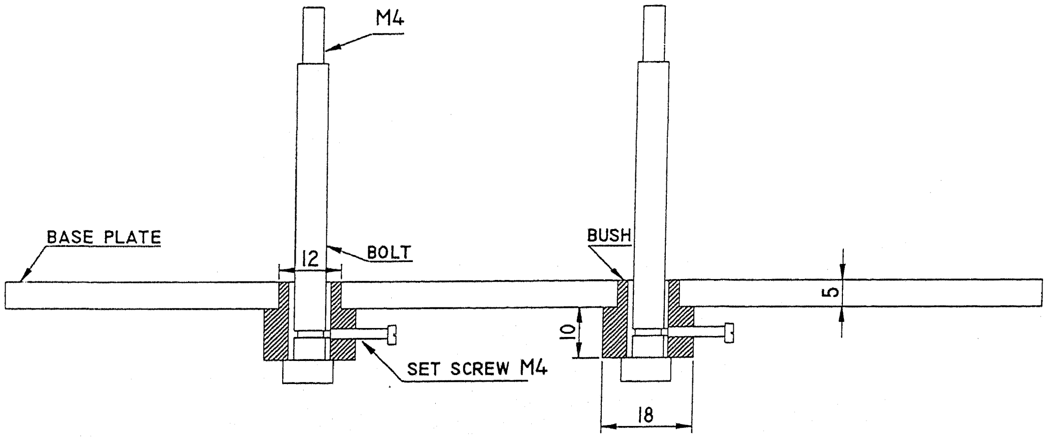

Figure 4.5 Base plate

Figure 4.6 Die-set with cylinderical pattern

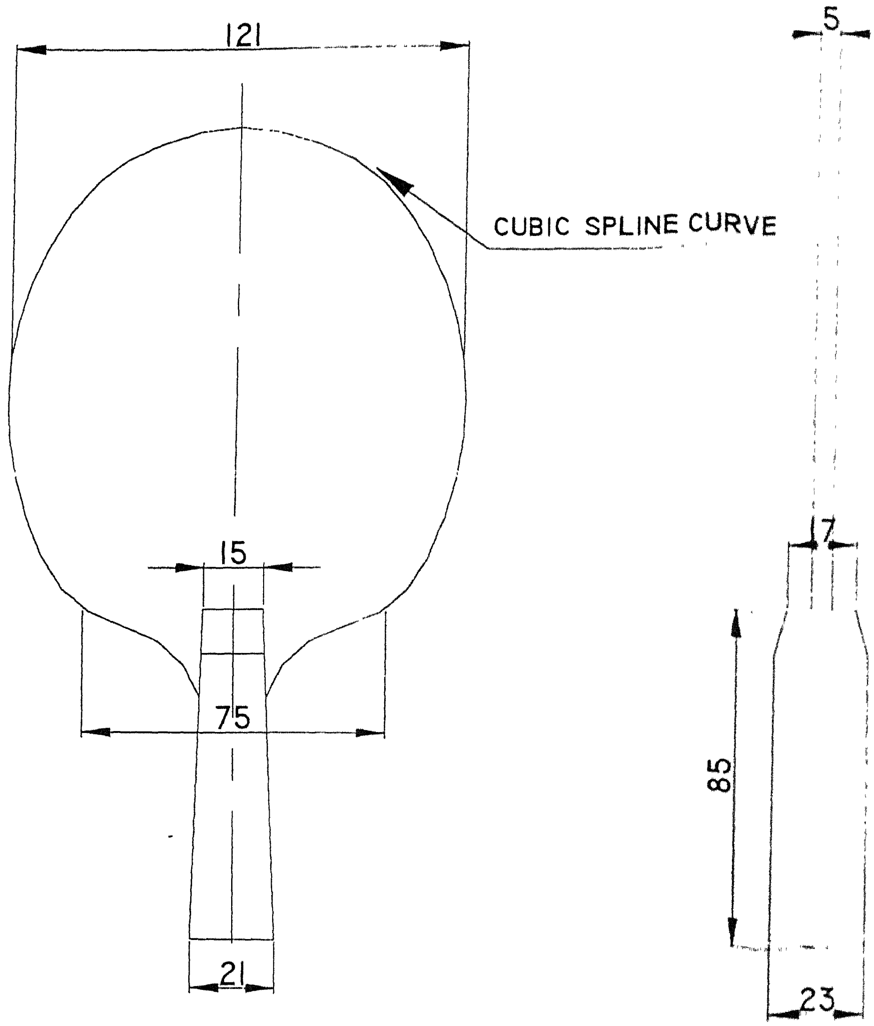

Figure 4.7 Detailed drawing of the product

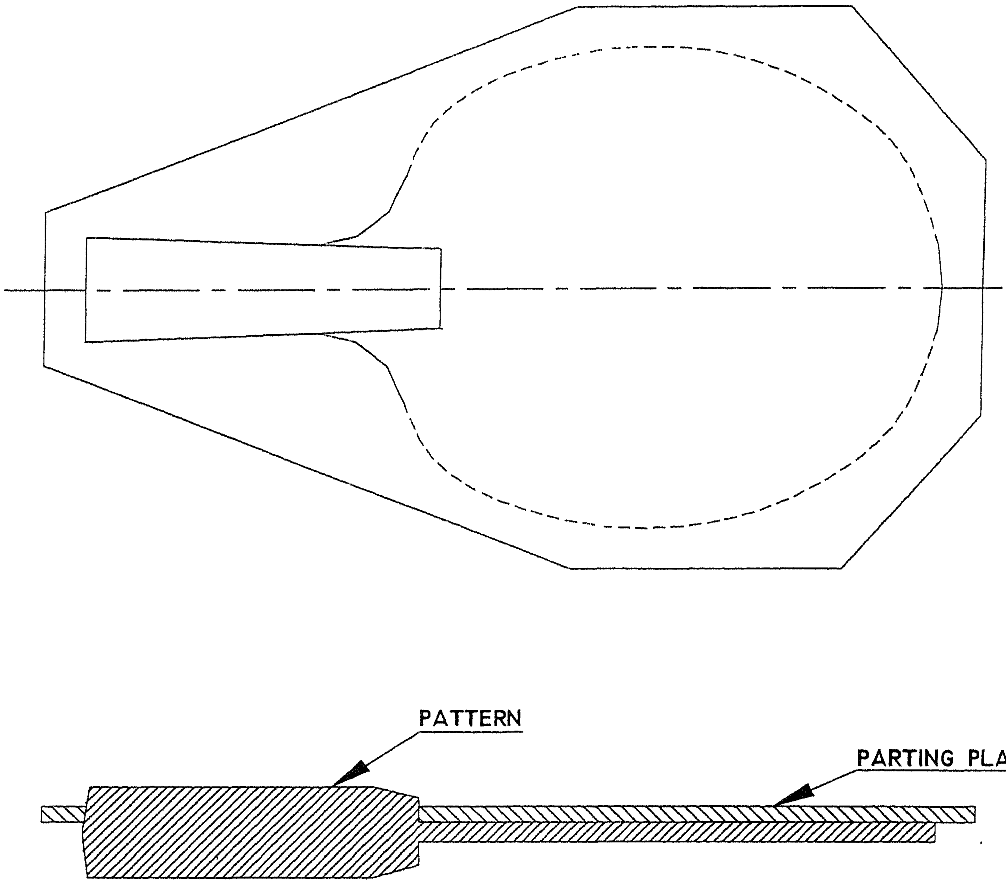

Figure 4.8 Pattern inserted in the parting plate

Figure 4.9: Die-set with table tennis bat pattern

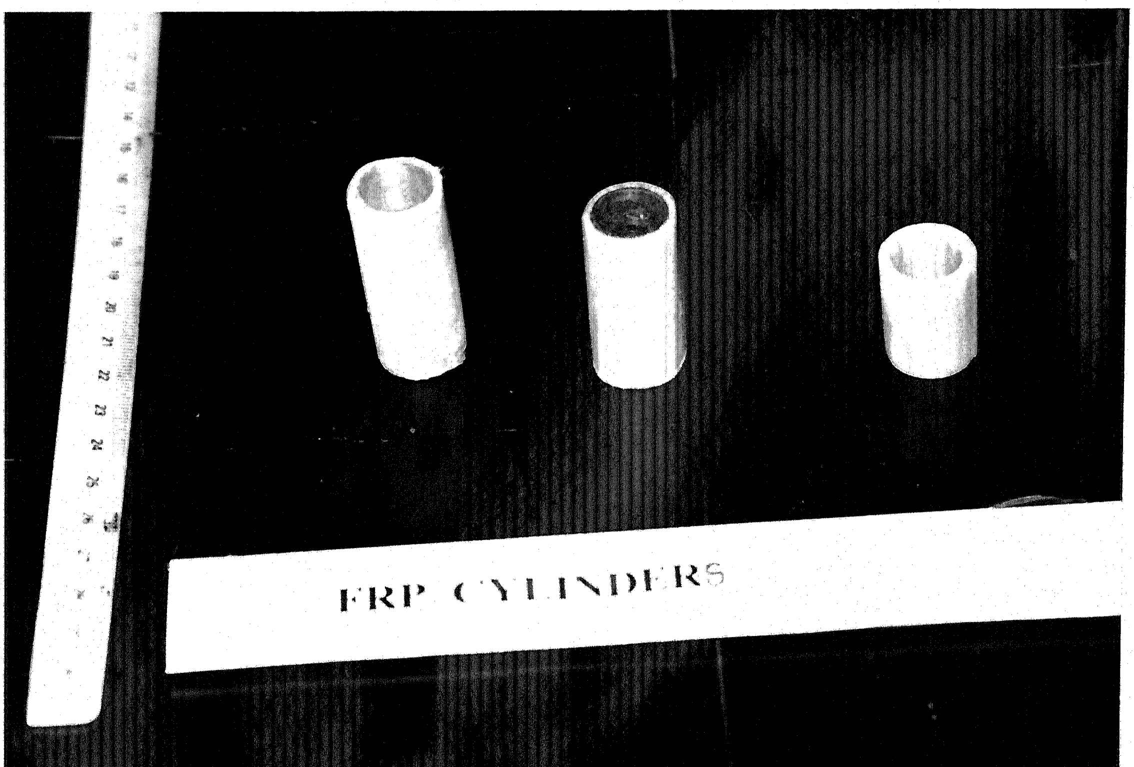

Figure 4.10: FRP Cylinders

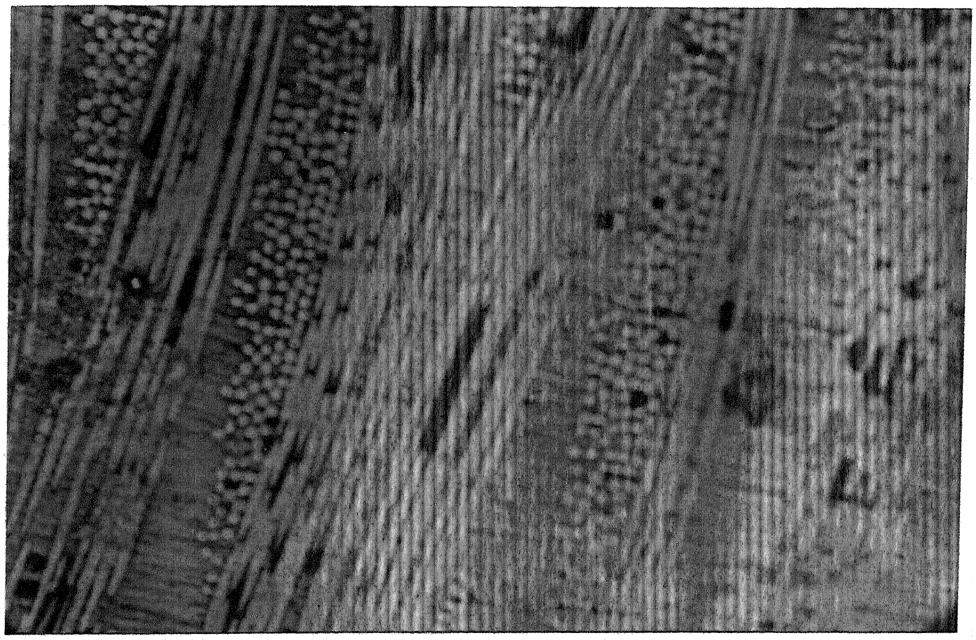

Figure 4.11 Optical microscopy of the FRP hollow cylinder

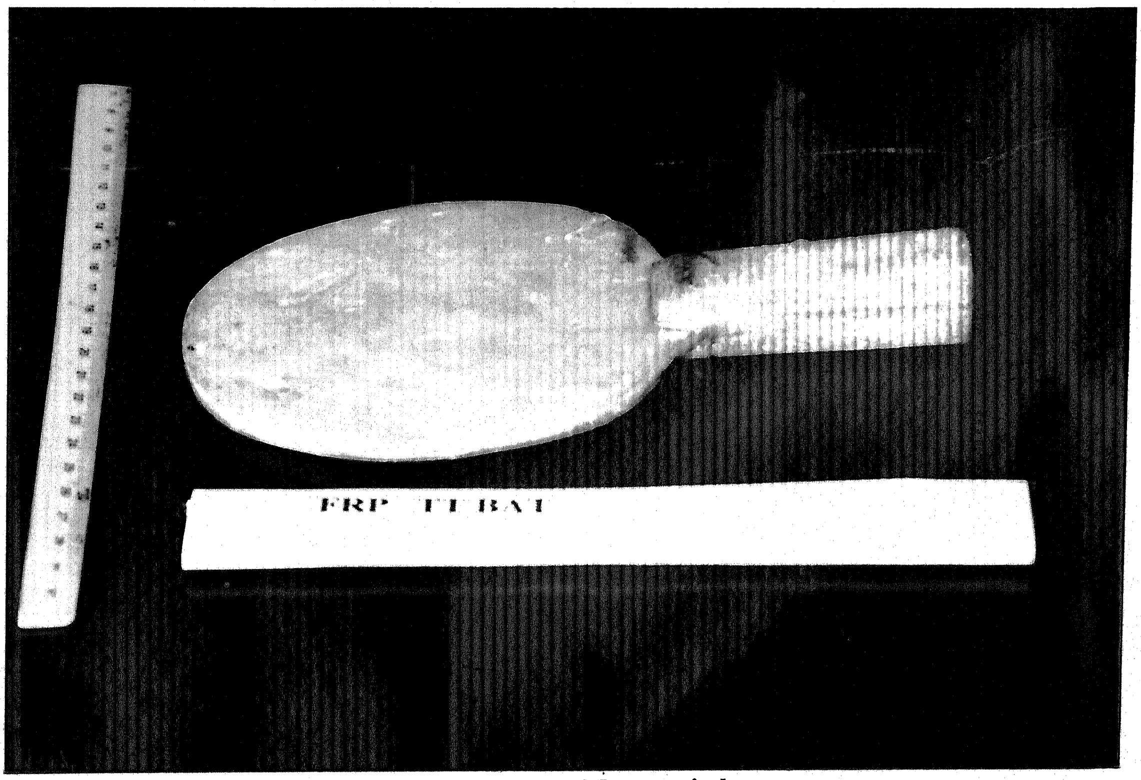

Figure 4.12 FRP Table tennis bat

CHAPTER 5

CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

5.1 CONCLUSIONS

The FRP (Fiber reinforced plastic) products are being manufactured and used, mostly by the aerospace industries due to its attractive properties like high strength, corrosion resistance, high modulus and light weight. These properties of the FRP composites can be exploited in daily life products. But the techniques for manufacturing FRP products, developed by aerospace industries, are very expensive and production rate is low. Thus for making FRP products for daily life, better production methods are to be developed, which should not be very expensive and production rate should be high. In present work, a new technique has been developed for manufacturing FRP products from fabric based prepregs. The technique is based on one of the indirect rapid tooling (RT) techniques, in which a pattern is used to make the moulds. In the technique, a matching die-set of a low temperature alloy of melting point 200° C is made by casting process. Die-sets (mould) for various FRP products are made. For manufacturing FRP products, a uncured preform of the product is prepared by stacking prepregs on the die-set layer by layer. This preform is cured under an appropriate temperature and pressure cycle. Using the technique, various FRP products like several flanged cones, several cylinders and a table tennis bat are made. For making die-sets from complex shaped patterns, a new method "Parting Line Concept" has been developed. Using the concept die-sets for various products are made like cylindrical product and table tennis bat. Several quality tests are conducted on the FRP products. On the basis of quality tests conducted on the

products, comparison is made between the products made by the rapid tooling and the conventional tooling. From the comparison, it is concluded that the quality of products made by rapid tooling is comparable to quality of the products made by conventional tooling. The rapid tooling has several advantages over the conventional tooling like less costly, does not require high expertise and simple process.

5.2 SCOPE FOR THE FUTURE WORK

1. It is recommended that an experimental set-up should be developed to manufacture die-sets and FRP products in vacuum, to avoid the formation of bubble pit on the die surface and better curing of the preform.
2. The technology should be further developed to make products of more complex shape.
3. One half of the matching die-set can be made of flexible material like silicon rubber to have more uniform pressure on various surfaces of a complex product.
4. Efforts should be made to link rapid tooling to rapid prototyping.

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